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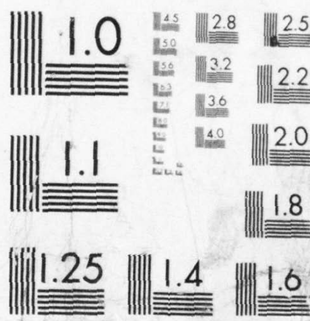
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TECHNICAL REPORT H-78-17

RIVER TOW BEHAVIOR IN WATERWAYS

Report 2

SECOND EXXON TEST PROGRAM

by

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October 1978

Report 2 of a Series

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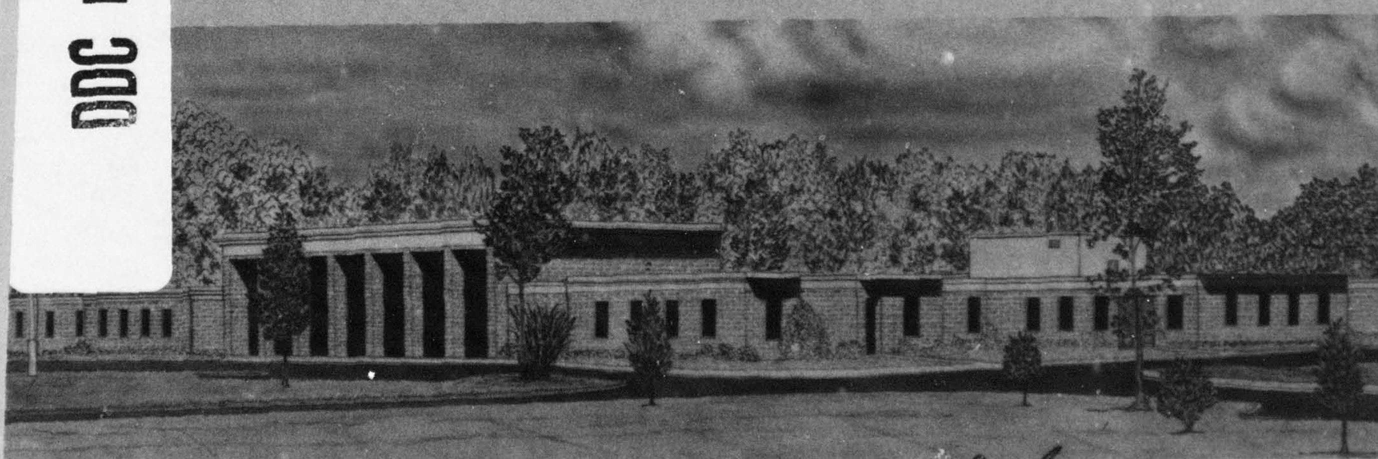

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This is the final report by R. M. Schulz Associates (RMSA) to the Corps of Engineers (COE) on Contract No. DACW39-77-C-0086 to obtain and analyze data on river tow behavior. This report describes the second full-scale river tow test program conducted in this country in which second-by-second records of tow position, attitude, rudder, power, and river environment parameters are obtained and analyzed. This study is an expanded version of the study format
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established during the first Exxon Co., USA (EXXON), test program.

In the latter part of November 1976, the first Exxon tow test program was conducted using an Exxon Co. owned and operated river tow. The tow was instrumented and a number of trial runs were made to determine the tow's speed-power, fuel consumption, and maneuvering performance. The tests took place in the Baton Rouge area on the Lower Mississippi River. The towboat employed in the test program, the EXXON MEMPHIS, was a twin screw, Kort nozzle towboat designed to push an integrated oil tow. The current series of tests performed in November 1977 using the EXXON NASHVILLE and EXXON LAKE CHARLES, open-wheel towboats, completed the comparative program to determine the propulsion efficiency of Kort nozzle and open-wheel propulsion systems. The EXXON MEMPHIS and EXXON NASHVILLE were identical designs with the exception of the Kort nozzle, while the EXXON LAKE CHARLES had about two-thirds of their installed power.

The initial Exxon test program, designed primarily to analyze Kort nozzle performance, was expanded to include participation by RMSA under COE sponsorship. RMSA's role was to measure and analyze tow position and steering behavior in addition to available horsepower data. The expanded test program provided Exxon and the COE with a cost-effective method of obtaining data on such dynamic performance elements as: steering response in turns; speed losses due to steering; acceleration and stopping distances; and Kort nozzle and open-wheel impacts on steering and propulsive efficiency.

This report contains the results of the Post-Trial Analysis activities. Section II describes the physical characteristics of the tows used in the trials. Section III describes the geography of the trial area, field survey activities, and current measurements undertaken to support the tow tests. Section IV describes the instrumentation, equipment, and procedures used during the trials. Section V and VI contain charts, graphs, and descriptions of the EXXON NASHVILLE and EXXON LAKE CHARLES steering tests. Section VII discusses the steering test performance. Section VIII describes the performance of the Exxon tows during straight course, speed-power runs. Section IX discusses the special backing and stopping tests performed. Section X describes the data reduction activities.

The Appendices and list of References follow Section X in which Appendix A lists the EXXON NASHVILLE test activity sequence and Appendix B lists the EXXON LAKE CHARLES test sequence. Appendices C and D give the shaft horsepower measurements obtained for the EXXON NASHVILLE and EXXON LAKE CHARLES, respectively. Appendix E contains the fuel measurements obtained by Exxon personnel for both tests and Appendix F shows a sample of the processed tow performance data. References follow Appendix F.

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PREFACE

The project described herein was undertaken by the U. S. Army Engineer Waterways Experiment Station (WES) for the Directorate of Civil Works, Office, Chief of Engineers, U. S. Army. The project was conducted by R. M. Schulz Associates in cooperation with the Exxon Company under Contract No. DACW39-77-C-0086. This study was a follow-on to a previous test performed in November 1976 by the Corps of Engineers and the Exxon Company and was to obtain tow performance data from full-scale measurements of tow maneuvers involving tows similar to the tow involved in the first test. This test program is the result of an expansion of the original tow performance test program that was originally planned by the Exxon Company.

The study was conducted under the general supervision of Mr. H. B. Simmons, Chief, Hydraulics Laboratory, and Mr. M. B. Boyd, Chief, Hydraulic Analysis Division. The contract monitor for the project was Dr. L. L. Daggett, Math Modeling Group. Mr. C. J. Huval, Math Modeling Group, provided advice and guidance on this study. Acknowledgement is given to Mr. J. L. Grace, Jr., Chief, Hydraulic Structures Division, and Mr. G. A. Pickering, Chief, Locks and Conduits Branch, for their support of this study.

Special acknowledgment is given to Messers. R. Schulz, R. M. Schulz Associates; M. Fedak, Exxon Company; and E. Shearer, Hillman Barge and Construction Co., for their cooperation, assistance, and advice in planning and conducting this test. The Exxon Company's generosity in sharing the recorded data and cooperation in expanding their planned test program is greatly appreciated.

Commander and Director of WES during this study and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

FOREWORD

This report is essentially a report about the establishment of a river tow performance data base. It attempts to draw conclusions about tow performance where possible, but in the main, portrays the conditions of the data acquisition rather than the analytical conclusions therefrom.

This report is also the cooperative product of several individuals and organizations and it is hoped that the final product meets their standards and with their approval. In particular, the Exxon Co. USA and their personnel in Baton Rouge and Houston deserve the warmest of accolades in recognition of their cooperation during the test program. Individuals in Exxon who contributed to the program are Myron Fedak, Captain Elmer Worley, John McCracken, and J.W. "Buck" McCreary. J. Serrette, J. Decker, D. Theriot and the crew of the EXXON NASHVILLE and I. Dupre, S. Calais and the crew of the EXXON LAKE CHARLES are commended for their cooperation and the skill exhibited during the tests. Special appreciation is extended to Ed Shearer of Hillman Barge and Construction Company (the towboat designer and builder)for providing technical detail on the tows.

Personal thanks to Bert Schulz for his efforts during the pretrial planning, field survey, and tow trials and to Cheryl Schulz and Jane Carter for their attention to detail during the data reduction and report preparation.

PROJECT SUMMARY

The project developed a tow behavior data base for analyzing dynamic performance in which:

- Over 9 hours of tow behavior data were provided describing the second-by-second variations in key performance parameters.
- Full power, reduced power, constant and variable rudder, and backing and stopping maneuvers were part of the computerized tow performance data base.

The project measured tow turning capability in a river bend in which:

- 5 upstream, steady rudder, constant power turns were computerized, charted and their key performance variables plotted.
- 5 downstream runs at constant power using variable rudder were similarly processed.

Special tests of tow behavior were made in which:

- 2 upstream and 2 downstream sets of Z maneuvers showed tow steering response and speed variations.
- Steady power backing established the tow's speed capability.
- 2 upstream and 4 downstream crash stops from full ahead power established stopping times and distances.

Straight-course, constant power runs over a measured course were made in which:

- Kort nozzle and open wheel towboat performance were compared.
- Fuel consumption levels were established at various powers.

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I. INTRODUCTION

This is the final report by R M Schulz Associates (RMSA) to the Corps of Engineers (COE) on contract number DACW39-77-C-0086 to obtain and analyze data on river tow behavior. This report describes the second full-scale river tow test program conducted in this country in which second-by-second records of tow position, attitude, rudder, power, and river environment parameters are obtained and analyzed. This study is an expanded version of the study format established during the first Exxon Co. USA (EXXON) test program [1].

In the latter part of November 1976, the first Exxon tow test program was conducted using an Exxon Company owned and operated river tow. The tow was instrumented and a number of trial runs were made to determine the tow's speed-power, fuel consumption, and maneuvering performance. The tests took place in the Baton Rouge area on the lower Mississippi. The towboat employed in the test program, the EXXON MEMPHIS, was a twin screw, Kort nozzle towboat designed to push an integrated oil tow. The current series of tests performed in November 1977 using the EXXON NASHVILLE and EXXON LAKE CHARLES, open-wheel towboats, completed the comparative program to determine the propulsion efficiency of Kort nozzle and open-wheel propulsion systems. The EXXON MEMPHIS and EXXON NASHVILLE were identical designs with the exception of the Kort nozzle, while the EXXON LAKE CHARLES had about two-thirds of their installed power.

The initial Exxon test program, designed primarily to analyze Kort nozzle performance, was expanded to include participation by RMSA under COE sponsorship. RMSA's role was to measure and analyze tow position and steering behavior in addition to available horsepower data. The expanded test program provided Exxon and the COE with a cost-effective method of obtaining data on such dynamic performance elements as: steering response in turns; speed losses due to steering; acceleration and stopping distances; and Kort nozzle and open-wheel impacts on steering and propulsive efficiency.

Figure 1.a provides an overview of the two Exxon test programs conducted by RMSA. The Pre-Trial Planning stage developed the program organization, defined and ordered the instrumentation, and established measurement techniques for the key parameters. The Trial Measurement stage undertook the field surveys, installed test equipment ashore and aboard the tows, obtained current measurements, and measured performance. The Post-Trial Analysis stage edited and coded the test data for the computer, developed or converted computer programs to process the test data, and analyzed tow performance during

PRE-TRIAL PLANNING

- Define Test Program
- Obtain Test Equipment

TRIAL MEASUREMENT

- Conduct Field Survey
- Install Shore Equipment
- Conduct Current Survey
- Install Onboard Test Equipment
- Measure Tow Performance
  - First Test-Exxon Memphis
  - Second Test-Exxon Nashville
    Exxon Lake Charles

POST-TRIAL ANALYSIS

- Review Test Measurements
- Code Performance Data
- Process Coded Performance Data
- Analyze Tow Performance

Figure 1.a Tow Test Program Overview

the trials. Table 1.A gives the individual participants in the November 1977 test program, their organization, and their primary test program responsibility. The Exxon staff in Houston was primarily responsible for coordinating the tow trial activities of the participants and measuring fuel consumption. Exxon Company U.S.A. had separately contracted the measurement and analysis of tow performance during the trials. The trial activities of the participants were established based upon their responsibilities in the first test.

The Trial Measurement activity in Baton Rouge conducted a field survey to mark sites for the positioning equipment ashore. Following the field survey, the positioning equipment was placed at the survey locations and readied for the tow trials by using the units to obtain current velocity measurements. The trials had been tentatively established as six test runs, 3 upstream and 3 downstream for each tow, as shown in Table 1.B. Appendix A and B list the test sequence actually followed. Test equipment was placed on each of the towboats the day before the trials with final hook-ups and calibration checks performed just prior to the trial runs. The trials lasted over eight hours for each tow.

Table 1.A

Test Participants

Organization	Individuals	Trial Acitivity/Title
Exxon	M. Fedak	Exxon Program Director
	E. Worley	Port Captain
	J. McCracken	Fuel Measurement
	J. McCreary	Repair Inspector
EXXON Contractor		Horsepower & RPM Measurement
Hillman	E. Shearer	Assist Test Personnel (Towboat Designer)
RMSA	R. Schulz B. Schulz	Field and Current Survey, RPM, Rudder, Position Measurement

Table 1.B

Tow Trial Sequence

Run	Straight Course, Speed-Power	EXXON* NASHVILLE	EXXON* LAKE CHARLES
1	Full Power, Upriver	FC	FC
2	" " , Downriver	FC	FC
3	3/4 Power, Upriver	FC	FC
4	1/2 " , Downriver	FC	FC
	Turns, River Bend		
1	1/2 Power, Upriver	FC	F
2	" " , Downriver	FC	F
3**	" " , Upriver	FC	F
4**	" " , Downriver	FC	F
5	" " , Upriver	FC	
6	" " , Downriver	FC	
	Other Tests		
1	Full Power, Crash Stop, Upriver	F	F
2	" " , " " , Downriver	F	F
5	" " , Zig-Zag, Upriver	FC	F
6	" " , " - " , Downriver	FC	F
6	" " , Crash Stop, Downriver	F	F
A	" " , Astern, Downriver	P	F

*F = Full set of measurements

P = Partial set of measurements

C = Performance can be compared with EXXON MEMPHIS performance

**3/4 Power for EXXON LAKE CHARLES

This report contains the results of the Post-Trial Analysis activities. Section II describes the physical characteristics of the tows used in the trials. Section III describes the geography of the trial area, field survey activities, and current measurements undertaken to support the tow tests. Section IV describes the instrumentation, equipment, and procedures used during the trials. Section V and VI contain charts, graphs, and descriptions of the EXXON NASHVILLE and EXXON LAKE CHARLES steering tests. Section VII discusses the steering test performance. Section VIII describes the performance of the Exxon tows during straight course, speed-power runs. Section IX discusses the special backing and stopping tests performed. Section X describes the data reduction activities.

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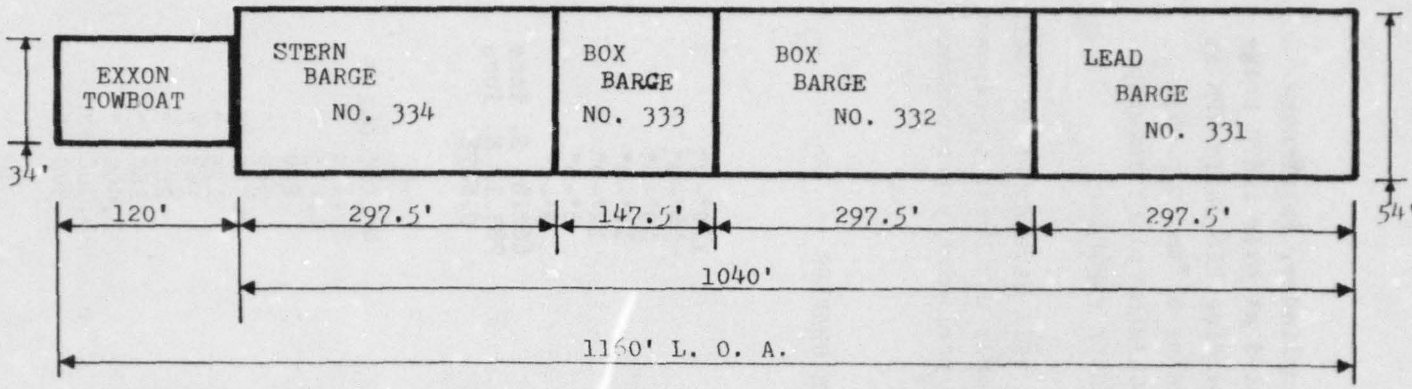
II. TOW CHARACTERISTICS

The tows tested during the trials were integrated oil tows owned and operated by Exxon Company USA. The barge string was composed of four (4) barges with the lead barge being a single-skin design with a modified scow bow and a square stern. The two middle barges were single-skin, box designs. The trailing barge was also a single-skin design with square end forward and shortened scow rake at the stern. The EXXON NASHVILLE and EXXON LAKE CHARLES were the two open-wheel towboats tested with this tow.

Figure 2.a shows the plan-view arrangement of the tow tested with the tow's dimensions, weights, centers of gravity, and wetted surface. The lead barge, No. 331, was equipped with a bow-thruster unit which was not used during the trials. The two lead barges, Nos. 331 and 332, and the two trailing barges, Nos. 323 and 324, and towboat are sized as separate units for separate locking through 600 foot long lock chambers. The single-string arrangement shown in Figure 2.a meant that the center of gravity of each unit was located along the centerline. This simplified computations since only the longitudinal center of gravity needed to be calculated.

During the tests, the barges were loaded to a mean draft of 9.25 feet with a cargo of 13,100 short tons of oil. The resulting loaded displacement of the barge string was 15,510 short tons. With the towboat's displacement of 783 short tons, the tow had a total displacement of 16,293 short tons. The primary dimensions and capacities of two towboats, shown in Table 2.A, were taken from plans, drawings, and documentation furnished by Exxon and Hillman. The towboat's principal propulsion characteristics are shown in Table 2.B. The EXXON NASHVILLE is an open-wheel towboat fitted with twin screws with over 3300 horsepower developed by two Fairbanks-Morse diesel engines. The EXXON LAKE CHARLES is also an open-wheel towboat similar to the EXXON NASHVILLE but only capable of developing 2600 shaft horsepower.



	Draft, (feet)	LCG, feet (Aft of Bow)	VCB, feet (Above Baseline)	Displacement (Short Tons)	Cargo Weight (Short Tons)	Wetted Surface* (Square Feet)
Barge No. 331	9.25	158.54	4.76	4,280	3,580	20,300
Barge No. 332	9.25	446.25	4.62	4,570	3,880	21,601
Barge No. 333	9.25	668.75	4.62	2,280	1,930	10,701
Barge No. 334	9.25	885.00	4.77	4,380	3,710	21,000
Towboat**	9.00	1091.86	5.07	783	---	5,729
Tow Total (Average)	(9.24)	(550.78)	(4.72)	16,293	13,100	79,331

*Square ends of barges not considered.
**Both the EXXON NASHVILLE and EXXON LAKE CHARLES.

Figure 2.a Tow Arrangement, Weight, and Center of Gravity Data

The EXXON NASHVILLE is powered by two 10 cylinder, Fairbanks-Morse Roots Blower engines. Each engine is rated at over 1,670 brake horsepower at 750 RPM with reduction gears providing 216 shaft RPM at that engine speed. The shafts are inboard turning at the top when the engines are moving ahead. The EXXON LAKE CHARLES plant develops proportionately less power from its two 8 cylinder engines.

Test bed data indicate that these engines will have specific fuel consumption rates ranging from 0.36 to 0.40 pounds per brake horsepower hour when burning 19,630 BTU's per pound. The preliminary performance

Table 2.A

EXXON NASHVILLE and EXXON LAKE CHARLES

<u>Dimensions</u>	
Length, Overall	120'-0"
Breadth, Molded	34'-0"
Depth, Molded, Main Deck at side	10'-6"
" " Top of Headlog	12'-0"
" " Top of Sternlog	12'-0"
Draft, Molded, Design Waterline	8'-0"
" " Load Waterline	9'-0"
Displacement, Molded (8'-0")	662.85 S. Tons
" " (9'-0")	783.12 S. Tons
Block Coefficient, Design Draft	0.6678
<u>Tank Capacities</u>	
Fuel Oil, 8'-0" Draft	41,800 Gal.*
" " Max.	76,100 "
Engine Lube Oil	1,015 "
Reduction Gear Lube Oil	290 "
Hydraulic Oil	350 "
Potable Water	6,500 "
Cleaning Fluid	175 "
Air Filter Oil	175 "
Dirty Lube Oil	260 "
Main Engine F. O. Bleed	260 "
Ballast	8,000 "
Slop	4,300 "
Sewage	4,300 "

* 41,000 Gal. For EXXON LAKE CHARLES

of the tows are compared in Figure 2.b which includes test data from the EXXON MEMPHIS tests [1] and describe a rather well defined horsepower curve. The EXXON MEMPHIS is fitted with Kort nozzles while the EXXON NASHVILLE and EXXON LAKE CHARLES are open-wheel designs. Of particular importance to the industry is the fact that the horsepower curve in Figure 2.b shows the EXXON MEMPHIS using slightly less horsepower than the EXXON NASHVILLE to achieve the same speed. This apparent Kort nozzle efficiency advantage is offset by the fact that the EXXON NASHVILLE tow carried 474 short tons more oil (3 percent greater displacement). The deeper water and stronger current during the EXXON NASHVILLE tests as well as possible non-optimized propeller characteristics also make strict performance comparisons difficult between the tows.

Table 2.B

EXXON NASHVILLE and EXXON LAKE CHARLES
Propulsion Data

Engine System

2 Fairbanks-Morse
Model 38D8 1/8, Roots Blower Diesels
2 Western Reverse Reduction Gears

Propulsion Characteristics	Exxon Nashville	Exxon Lake Charles
Cylinders per Engine	10	8
Rated Brake Horsepower	3,334	2,670
Number of Shafts	2	2
Rated Engine RPM (Ahead)	750	750
Shaft RPM @ 750 ERPM	216	199
Rated Towing Speed, MPH	10.2	9.7
Gear Ratio, Ahead	3.47	3.766
" " , Astern	3.62	4.01

Propeller Characteristics (Open Wheel)		
Diameter, D, Feet	8.5	8.5
Mean Pitch, P, Feet	7.25	7.0
Pitch Ratio, P/D	0.8529	0.8235
Disc Area, Sq. Ft.	56.745	56.745
Number of Blades	4	4
Projected Area, Sq. ft.	38.18	37.94

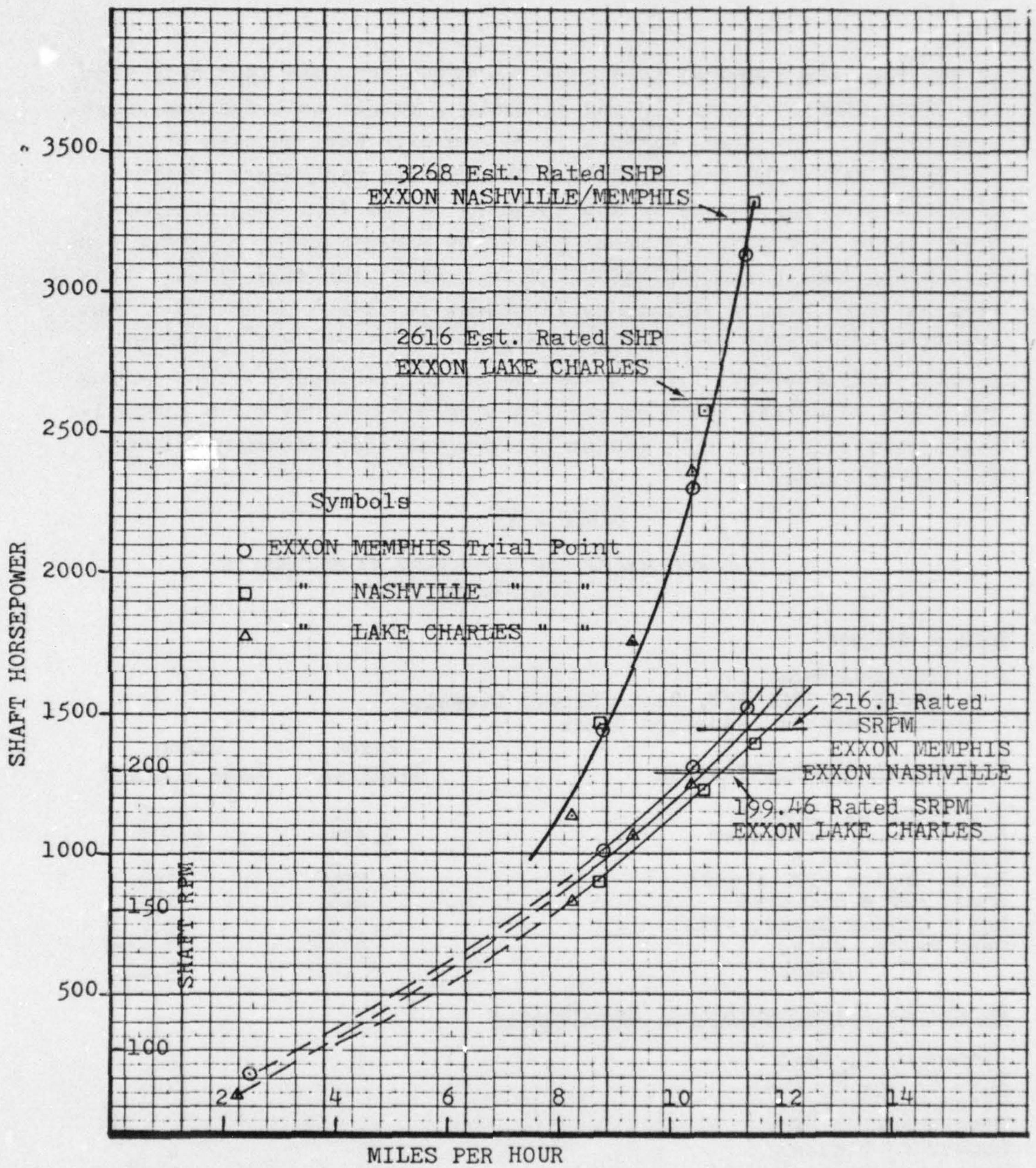


Figure 2.b Speed-Power Performance Curves

III. TRIAL COURSE GEOGRAPHY AND FIELD SURVEY ACTIVITIES

This section of the report describes the physical characteristics of the river area where the tow trials were held and the related survey activities and waterway environment tests which were performed. Section 3.1 describes the general layout of the test course and the placement of electronic shore reference stations used to measure tow and survey boat positions. Section 3.2 describes the X,Y plane coordinate system used to locate the shore reference stations and tabulate tow movements. Section 3.2 describes the current measurement survey which was performed before and after the tow trials which obtained depth measurements as well as X,Y coordinates for current velocity. These current measurements were considerably more comprehensive than normally collected during full-scale test programs.

3.1 Overview of Trial Course Geography

The trial course area used during the November 1977 Exxon tow tests was virtually identical to the river segment used during the 1976 Exxon trial. The trial course was established off of Baton Rouge as shown in Figure 3.a. The primary trial area was a straight, north-south section of the river marked by three ranges located on the western side of the river south of the U.S. 190 Bridge. The second trial area segment was Wilkinson Point bend north of the 190 Bridge. Figure 3.a provides an overview of the trial course geography showing the principal landmarks, shore reference station (transponder) locations, and trial course ranges. These points were labelled alphabetically in Figure 3.a to facilitate discussion in the text and comparison with coordinates and distances given later in Table 3.A. The most visible landmarks in the area were the State of Louisiana Capitol Building located on the east side of the river and the east and west support towers for the Gulf States Utilities cable crossing (A, B and C, respectively, Figure 3.a).

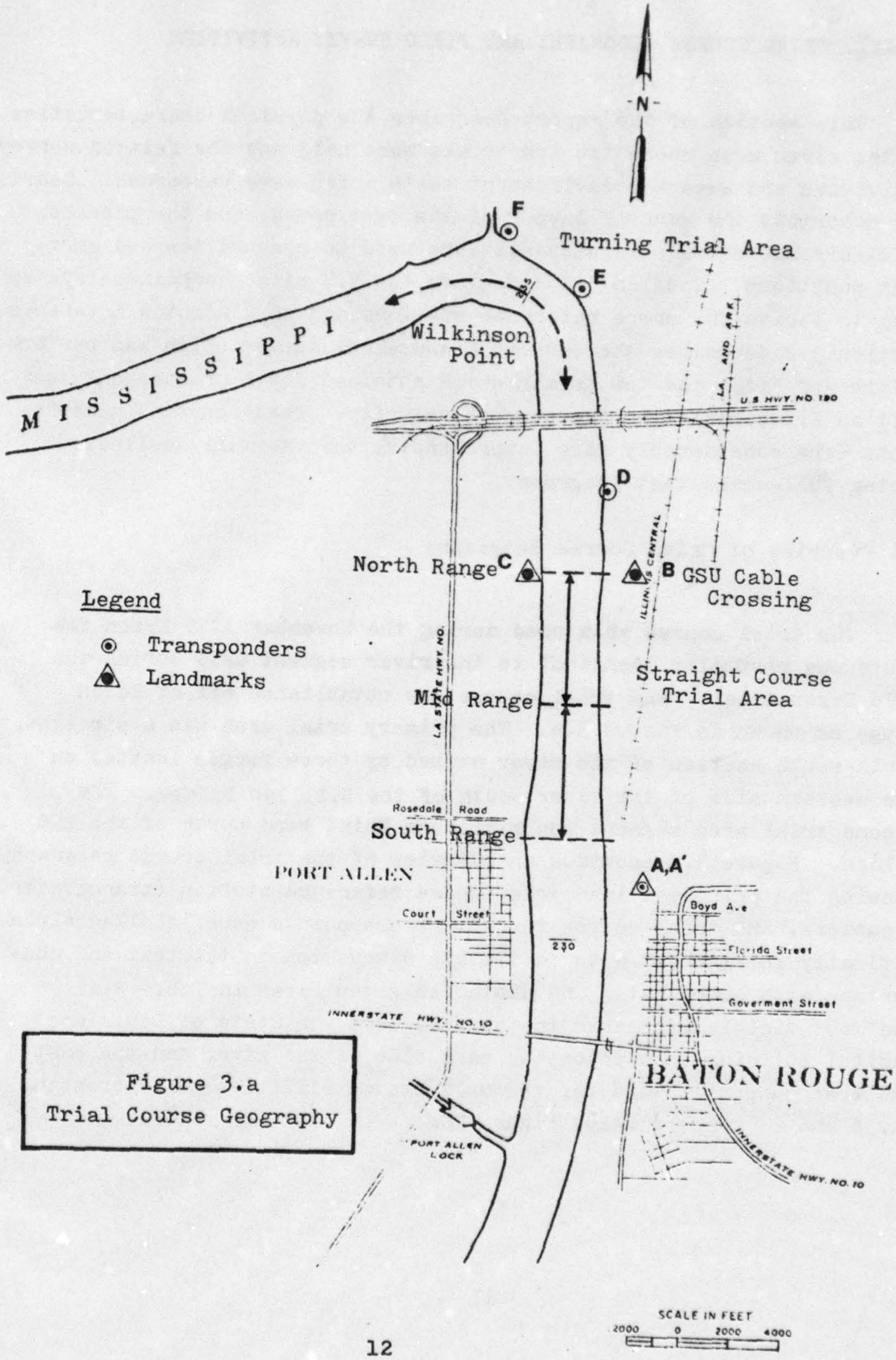


Figure 3.a
Trial Course Geography

The straight-course portion of the trial area, marked at the northern end by the Gulf States Utilities towers, extended southward 2.041 miles (between Mile 230.8 and 232.8). Range markers along the west bank marked each end of the course and an intermediate point 0.987 miles below the north range (shown by dashed lines in Figure 3.a). The second trial course area was the river bend north of the 190 Bridge. Established to measure the tow's path and behavior when negotiating turns, tow movements in this area were marked by the placement of two transponders shown as E and F in Figure 3.a.

Both trial areas presented major physical problems in placing the transponders due to the lack of high elevations with unobstructed views of the river, the long and relatively narrow test course, and the numerous steel structures such as piers, bridges, and towers which were serious constraints to the use of line-of-sight, shore based, distance ranging equipment. To meet these constraints, the following factors were considered:

1) Transponders were placed to give 2 transponders a clear line-of-sight to each tow antenna over a given river segment.

2) The projected intersecting angle between signals from two transponders was kept as close to 90° as possible.

3) Each transponder was positioned so that the tow's antenna would fall primarily within the transponder's maximum signal strength.

4) The four transponders were placed where they could be serviced and where they were secure from theft. Transponders 2 and 4 were placed and serviced by boat while Transponders 1 and 3 were placed on property where 24 hour security arrangements existed.

The placement of the transponders considered the waterway segments north and south of the 190 Bridge as two distinct trial areas due to the signal reflecting character of the 190 Bridge. Figures 3.b, 3.c, 3.d, and 3.e were photographs taken of the river segment below the 190 Bridge. Figures 3.b and 3.c were taken from the Transponder 1

Figure 3.b

I-10 Bridge (Arrow) and Mississippi River south of the test course as viewed from the #1 Transponder site on the Capitol Building. This area normally had 1 or more ships at anchor.

Figure 3.c

Straight course test area of the river from #1 Transponder site. Note transponder mounted atop light mast (Arrow).

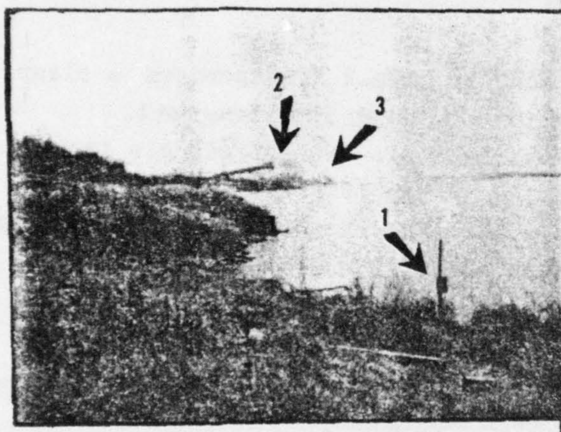
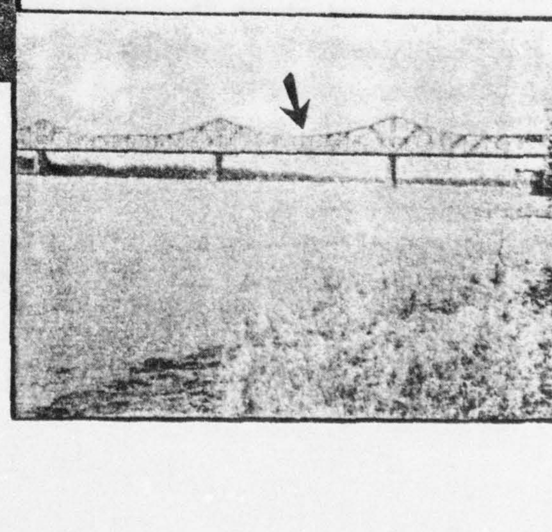


Figure 3.d

#2 Transponder site (Arrow 1) looking south over straight test course. Arrow 2 points to the Allied Chemical pier, Arrow 3 to the Exxon pier.

Figure 3.e

190 Bridge, Wilkinson Point (Arrow) and bend test area as seen from the #2 Transponder site.



site on the Capitol Building. Figure 3.b shows the river area south of the straight trial course with the arrow pointing toward the I-10 Bridge. Figure 3.c shows the trial course north of Transponder 1 with the arrow pointing out the transponder mounted atop the light mast on the 30th floor.

Figure 3.d and 3.e are photographs of the river taken from the Transponder 2 location. Figure 3.d shows the Transponder 2 site (Arrow 1) and the test course to the south with the Allied Chemical pier (Arrow 2) and the Exxon pier (Arrow 3) allowing a clear line-of-sight to I-10 Bridge. Figure 3.c shows the area north with the arrow at mid-span of the 190 Bridge pointing toward Wilkinson Point.

Figures 3.f and 3.g are photographs of Wilkinson Point bend area from the Transponder 3 site on the Scott's Bluff area of Southern University. Figure 3.f shows an oil tow making the turn headed up river (Arrow 2) around Wilkinson Point (Arrow 1). Figure 3.g shows the same tow (Arrow 1) further through the turn along with the Transponder 4 site (Arrow 2).

3.2 Transponder Field Survey Results

Prior to the river tow trials, a field survey was made to define geographic coordinates for each of the four transponders. Because accurate tow position measurements were required during the trials, triangulation data for transponders 2, 3, and 4 were obtained using a theodolite to measure angles between known landmarks. Also, since Transponder 1 was located on a known landmark its coordinates were obtained by direct measurement.

Field surveys often use both distance and angular measuring devices to derive a complete coordinate mapping of a test area. This method was outside the scope of the project with the result that the field

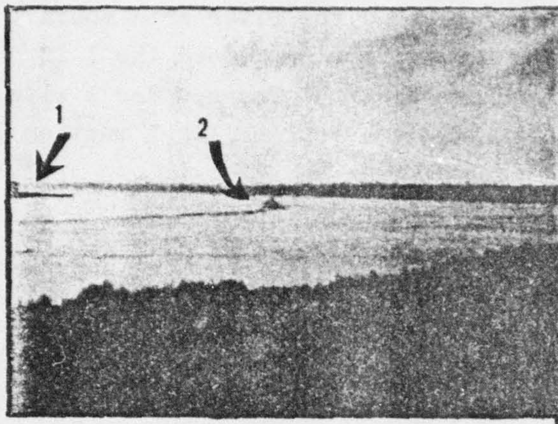


Figure 3.f
View of river bend area showing Wilkinson Point (Arrow 1) and oil tow (Arrow 2) in the first part of the turn looking westward from #3 Transponder site. Note the fleeting area under Arrow 1.

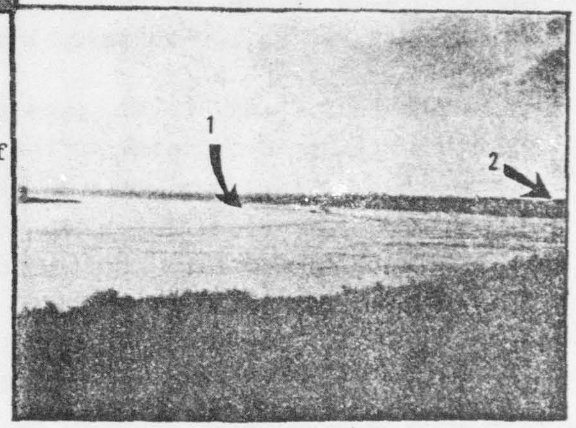


Figure 3.g
River bend with oil tow (Arrow 1) completing turn showing location of #4 Transponder (Arrow 2). The photograph was taken from Transponder 3.

survey relied solely upon bearings taken of landmarks whose coordinates had already been tabulated by the National Geodetic Survey [2]. Geographic representation of a reference system used an X,Y plane coordinate system with Y positive north. This data, published by the National Geodetic Survey for each state, converted landmark latitude and longitude data into earth-surface, plane coordinate data in feet [3].

Horizontal bearings of the landmark structures were taken from three transponder sites. These bearings, together with the known distances between each landmark, provided the necessary data from which to compute X,Y coordinates. The position of each transponder, shown in Table 3.A, was computed using "three-point resection" techniques [4] and standard plane geometric constructions.

Table 3.A

Test Course Reference Points, Coordinates, and Distances

Landmark	Latitude (North)	Longitude (West)*
A. Capitol Dome	30-27-29.294	90-11-14.186
B. East Power Tower (GSU)	30-29-29.308	91-11-26.861
C. West Power Tower (GSU)	30-29-29.258	90-12-09.686

	Lambert Plane Coordinates	
Survey Points	X(Feet)	Y(Feet)
A. Capitol Dome	2046021.62	651035.54
A'. #1 Transponder	2046010.37	651046.29
B. East Power Tower (GSU)	2044896.57	663619.29
C. West Power Tower (GSU)	2041149.64	663609.83
D. #2 Transponder	2044064.84	666815.44
E. #3 Transponder	2042901.99	674309.91
F. #4 Transponder	2039756.65	676024.98

Course Distances

From		To	Feet
A	-	A'	15.56
	-	B	12,633.94
	-	C	13,485.14
	-	D	15,900.76
	-	E	23,482.51
	-	F	25,762.80
A'	-	D	15,888.71
	-	E	23,470.37
	-	F	25,749.64
B	-	C	3,746.94
D	-	E	7,584.15
	-	F	10,167.41
E	-	F	3,582.55

*Letter designations correspond to those appearing in Figure 3.a, page 12.

3.3 Current Measurement Results

Current measurements were taken at 24 places along the test course to provide a means of estimating current impact on tow performance during the analysis. The current measurement locations were chosen to define a reasonably comprehensive picture of current speed and direction over each test area--the Wilkinson Point bend area and the straight course test area. Four cross-section locations above the 190 Bridge and four locations between the I-10 Bridge and 190 Bridge were selected. At each location, three current measurements were taken to define velocity vectors across that section of river--one measurement on each side of the assumed channel and one measurement in the center.

A survey boat fitted with "sea anchors", a miniranger positioning unit, and a fathometer was used to obtain current and depth measurements. The boat was taken as close as possible to a predetermined pair of transponder range coordinates and allowed to drift from that point. In theory, it should have been possible to position the survey boat within ±10 feet of a predetermined point. However, because of miniranger signal variations, river traffic, and the need to perform all of the tests in clear weather during daylight, it was impractical to spend much more than 30-60 seconds attempting to match transponder coordinates.

Figure 3.h shows the equipment arrangement aboard the survey boat. Three 20-gallon barrels were used as sea anchors and were supported by lines from the boat's deck so that the bottom of each barrel was 9 feet below the surface (9 feet was the approximate draft of the Exxon tows).

A current measurement sequence began by bringing the boat to the approximate coordinate position given by the precalculated transponder

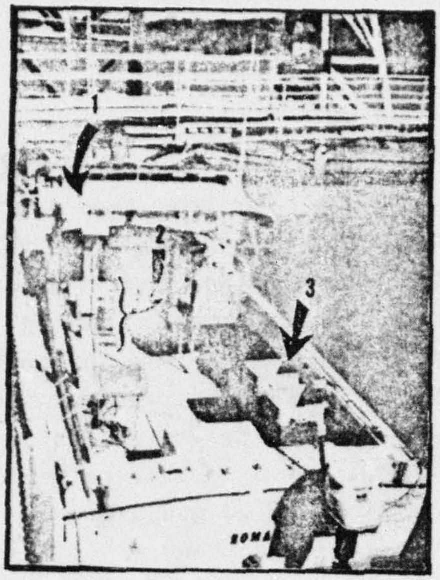


Photo of Survey Boat Equipment

1. Minirange Antenna
2. Console, Printer, Fathometer
3. "Sea Anchors" in Boat

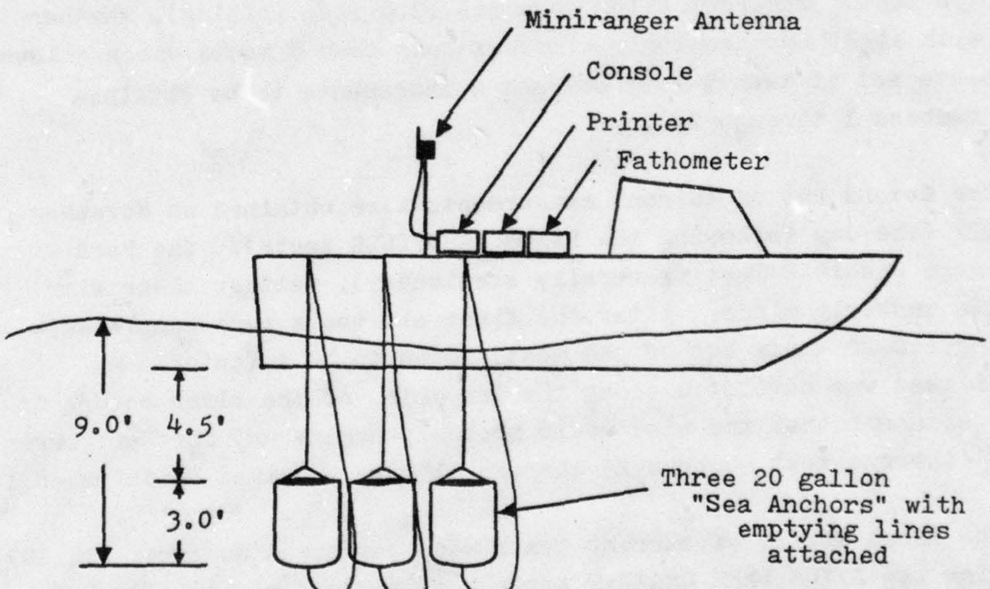


Figure 3.h Current Measurement Equipment Arrangement

ranges. The boat was then brought dead in the water, the engine shut off and the three barrels lowered over the side. The boat then drifted from 3 to 6 minutes during which time miniranger printouts were obtained at about 6 second intervals together with fathometer readings manually recorded every 18 seconds. This drift period normally covered some 500-1000 feet. The barrels were then brought back into the boat, the position and depth data collected, and the engine started and the boat moved to the next position. Each positioning, drift, and repositioning cycle took between 8 and 15 minutes. As a result, between 4 and 6 hours were required for the entire group of 24 measurements (8 river cross-sections, 3 measurements per cross-section).

In total, 58 current measurements were taken on 3 separate days. November 6, 1977 was the first day of current tests, 2 days before the first tow test. The Port Allen gage was 13.6 feet (rising), weather clear with light northwesterly winds of less than 5 knots which allowed a complete set of twenty-four current measurements to be obtained (test numbers 1 through 24).

The second set of current measurments were obtained on November 10, 1977 (the day following the EXXON NASHVILLE tests). The Port Allen gage was 14.8 feet (generally stationary), weather clear with variable westerly winds. After the first six tests were completed, the wind (10-20 knots out of the west) began to be a factor. A seventh test was completed along the lee side of the river before it became apparent that the wind would probably negate any further current tests. Current test numbers 25 through 31 were obtained on November 10.

The final series of current tests were performed November 11, 1977 following the EXXON LAKE CHARLES tests the previous night. The Port Allen gage was 14.9 feet (stationary) with northwesterly winds of 5-10 knots. A complete set of 24 current measurements were obtained together with 3 supplemental measurements. These tests were numbered 32 through 58.

Each sequence of 24 current measurements began above Wilkinson Point and progressed downstream with the last series of measurements being taken approximately due west of the Capitol Building. The 58 current tests were numbered sequentially with test number 58 being the last test performed November 11, 1977.

Figure 3.i shows the current tests made in the Wilkinson Point bend area and in the northern straight-course test area. Each of the arrows in Figure 3.i define the beginning and ending position of a drift segment. The number alongside the arrow is the number of the current test. Table 3.B lists the computed current velocity characteristics for each test performed above the 190 Bridge. Figures 3.j and 3.k show the location of the current tests performed in the straight-course test area. Table 3.C describes the computed current velocity characteristics for these tests.

The values shown in Tables 3.B and 3.C were obtained by computing X and Y coordinates for each pair of range readings. The X and Y velocity vectors (X' and Y') were derived as the slope of a linear least-square regression line fitted to five X (or Y) values about a given point. The X, Y, depth, and X' and Y' in Tables 3.B and 3.C were computed as arithmetic means obtained by excluding the first 2 and last 2 values from averaging calculations. The resultant velocity V and the true direction were then obtained directly from the X', Y' values given in the tables.

Because of the difference in gage height between the November 6 and November 10, 11 current tests, the November 6 current test results were excluded from the analysis. The Port Allen gage levels ranged from 14.5 feet on November 8 to 14.8 feet on November 11, 1977 which made the water level about 12 feet above the Low Water Reference Plane (LWRP). Figures 3.i, 3.j, and 3.k show the location of river cross-sections labeled A through N for which charted depth profiles were

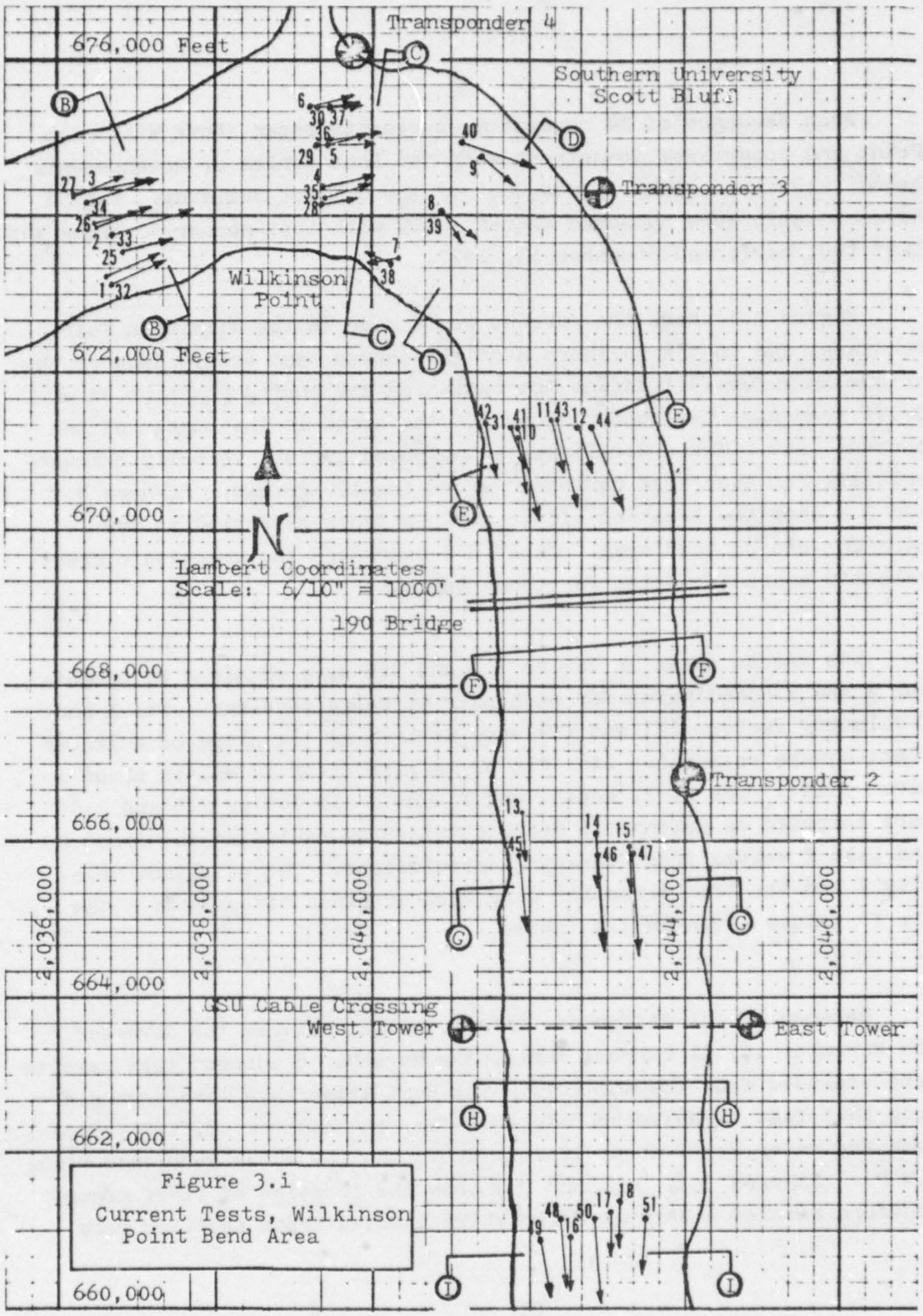


Figure 3.i
Current Tests, Wilkinson Point Bend Area

Table 3.B

Current Tests, Wilkinson Point Bend Area
(Average Values)

	Test	Coordinates, Ft[a] X	Coordinates, Ft[a] Y	Depth Ft	Velocity, FPS[b] X'	Velocity, FPS[b] Y'	Velocity, FPS[b] V	Direction ° True
Nov. 6	1	73,353	36,943	55	1.87	4.02	4.43	65
	2	73,986	36,818	51	1.72	4.91	5.21	71
	3	74,348	36,501	50	1.66	4.03	4.36	68
	4	74,475	39,686	111	0.96	4.22	4.33	77
	5	74,971	39,691	118	0.64	3.67	3.73	80
	6	75,447	39,483	94	0.74	3.10	3.10	76
	7	73,411	40,162	38	-0.25	-1.32	1.34	259
	8	73,870	41,136	120	-1.89	2.17	2.87	131
	9	74,594	41,608	109	-2.35	2.53	3.45	133
	10	70,845	41,929	35	-3.92	0.55	3.96	172
	11	71,112	42,333	67	-3.54	1.05	3.69	164
	12	71,027	42,749	94	-3.67	1.22	3.87	162
Nov. 10	25	73,633	37,122	56	0.88	4.64	4.73	79
	26	74,017	36,764	51	1.05	4.70	4.82	77
	27	74,378	36,600	53	1.14	4.66	4.80	76
	28	74,198	39,584	83	0.26	2.74	2.75	84
	29	74,933	39,670	116	0.05	4.15	4.15	89
	30	75,422	39,529	91	0.72	3.47	3.55	78
	31	71,078	41,906	35	-4.36	1.35	4.56	163*
Nov. 11	32	73,302	36,994	56	1.97	4.14	4.58	65
	33	73,928	37,226	55	1.56	4.96	5.20	73
	34	74,299	36,819	50	1.40	4.40	4.61	72
	35	74,338	39,646	97	1.23	3.42	3.64	70
	36	75,025	39,773	120	0.68	4.13	4.19	81
	37	75,393	39,677	102	0.46	3.38	3.41	82
	38	73,484	40,088	42	0.39	-1.18	1.25	288
	39	73,861	41,009	105	-1.91	1.33	2.33	145
	40	74,744	41,790	82	-1.10	2.37	2.61	115
	41	70,702	41,982	38	-3.76	0.69	3.83	170
	42	71,013	41,511	22	-2.89	0.58	2.94	169
	43	70,876	42,482	70	-3.64	0.90	3.75	166
	44	70,863	42,980	80	-4.40	1.51	4.65	161

a. X and Y coordinates refer to transformed Lambert plane coordinates for this section of Louisiana. X = Lambert Y minus 6×10^5 feet, positive north. Y = Lambert X minus 2×10^6 feet, positive east.

b. Current velocity vectors in feet per second, $V^2 = X'^2 + Y'^2$.

*Wind affected.

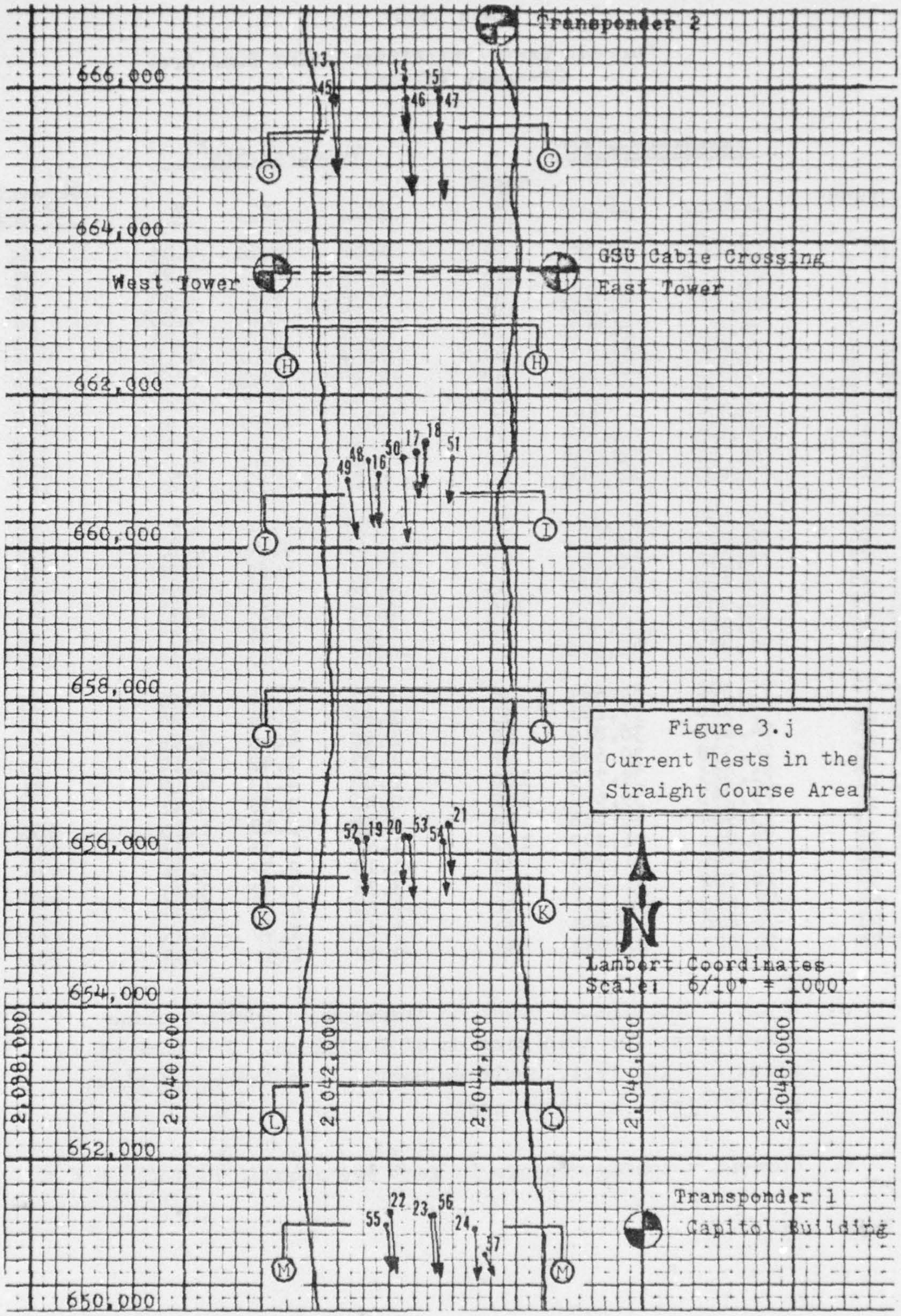


Figure 3.j
Current Tests in the
Straight Course Area

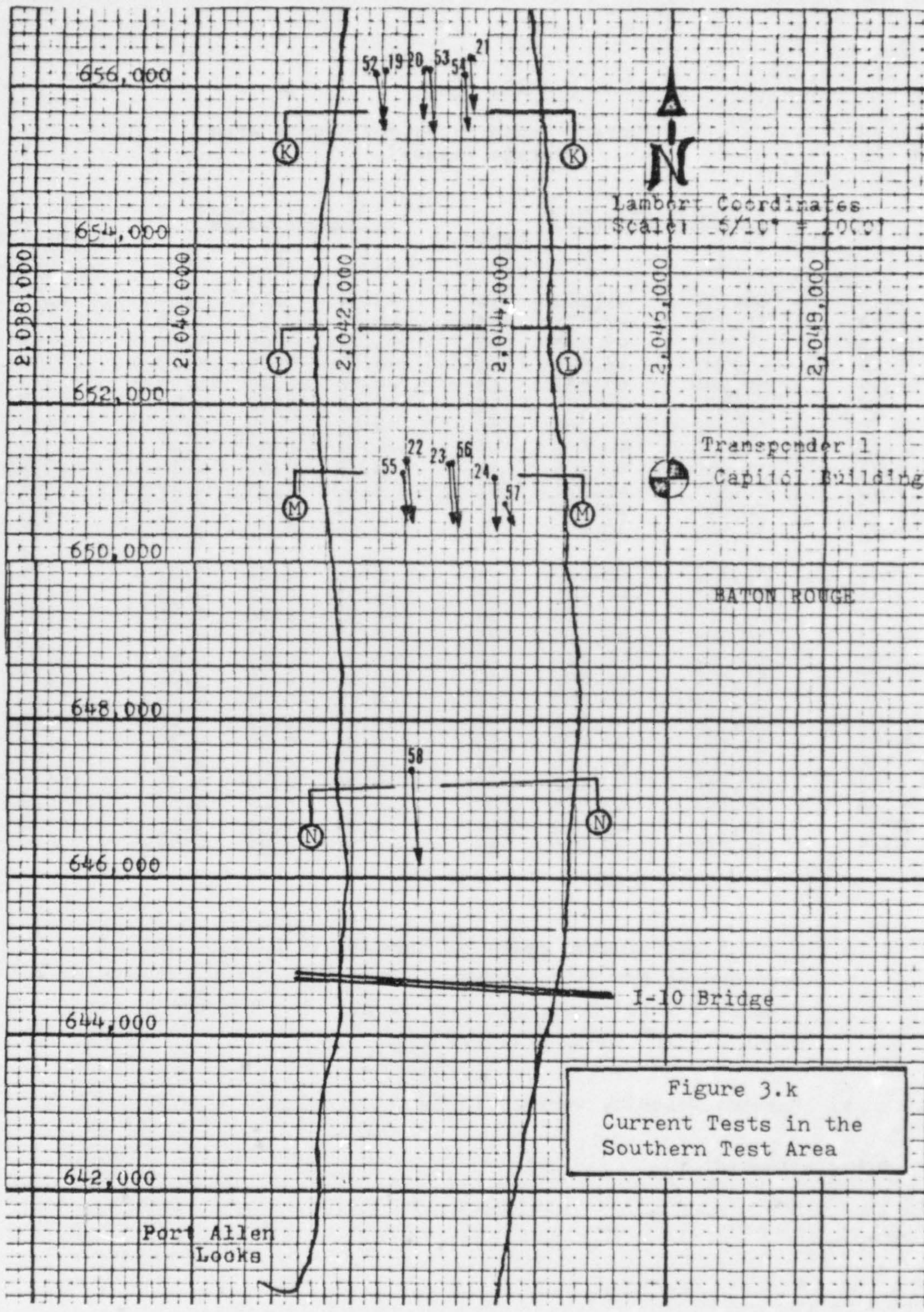


Figure 3.k

Current Tests in the Southern Test Area

Table 3.C

Current Tests, Straight Course Area
(Average Values)

	Test	Coordinates, Ft[a] X	Coordinates, Ft[a] Y	Depth ft	Velocity, FPS[b] X'	Velocity, FPS[b] Y'	Velocity, FPS[b] V	Direction ° True
Nov. 6	13	66,054	41,961	30	-3.34	0.14	3.34	178
	14	65,758	42,873	56	-4.18	0.18	4.18	177
	15	65,625	43,298	68	-3.71	0.01	3.71	180
	16	60,647	42,548	55	-4.23	0.09	4.23	179
	17	60,940	43,058	58	-4.70	-0.14	4.70	182
	18	61,086	43,114	58	-4.10	-0.07	4.10	181
	19	55,860	42,366	68	-4.42	-0.23	4.42	183
	20	55,910	42,851	55	-4.47	-0.05	4.47	181
	21	56,060	43,506	44	-4.18	0.40	4.20	175
	22	50,887	42,731	47	-4.35	0.33	4.37	176
	23	50,868	43,217	37	-3.59	0.26	3.60	176
	24	50,541	43,820	34	-2.76	0.07	2.76	179
Nov. 11	45	65,161	41,967	33	-3.00	0.22	3.01	176
	46	65,178	42,931	55	-4.33	0.19	4.33	177
	47	65,208	43,365	68	-4.35	0.26	4.36	177
	48	60,709	42,425	55	-4.32	0.23	4.33	177
	49	60,520	42,219	57	-4.39	0.66	4.44	171
	50	60,606	42,895	56	-5.08	0.14	5.08	178
	51	60,816	43,464	68	-4.76	-0.26	4.76	183
	52	55,834	42,336	68	-4.67	0.29	4.68	176
	53	55,871	42,978	53	-4.29	0.30	4.30	176
	54	55,839	43,404	46	-4.50	0.43	4.52	175
	55	50,966	42,692	48	-4.30	0.56	4.34	173
	56	50,896	43,305	37	-4.23	0.45	4.26	174
	57	50,655	43,952	30	-3.29	1.19	3.50	160*
	58	46,752	42,810	53	-4.75	0.36	4.76	176

a. X and Y coordinates refer to transformed Lambert plane coordinates for this section of Louisiana. X = Lambert Y minus 6×10^5 feet, positive north. Y = Lambert X minus 2×10^6 feet, positive east.

b. Current velocity vectors in feet per second, $V^2 = X'^2 + Y'^2$.

*Wind affected.

available [5]. The depth profiles, tabulated at about 80 foot intervals, had 12 feet added to adjust for the gage height during the tests. Cross-section A was west of cross-section B and was omitted from Figure 3.i.

River profile sections A through N were plotted in Figure 3.1 to show the contour of the waterway over the test area from north to south. Figure 3.1 lists the transformed coordinates for the west/south and east/north points where the river section intersects the shoreline. The area and width of the river were calculated for each of the sections in Figure 3.1 to assist in evaluating current velocities and probable discharge rates.

Cross-sections B through E and G, I, K, M and N in Figure 3.1 were given numbered points corresponding to the point where a given current test (November 10 and 11) intersected that river section. The upper points were shown 4.5 feet below the water surface indicating the mean depth at which the current velocity data was collected. The lower point relates to the corresponding depth of water recorded by the fathometer during that current test. The depth profiles taken from Reference 5 and the fathometer readings obtained during the current tests appear to be in reasonably close agreement with the exception of river sections C and D across Wilkinson Point bend. These areas had mid-channel fathometer depths 25 feet less than those indicated in Reference 5. In the test area south of 190 Bridge, the depths obtained by fathometer indicated that scouring had occurred and that the river depth was about 5 feet deeper than those given in Reference 5. However, due to the generally close agreement between published and measured depths, the published data were primarily used to estimate depth of water under the tow over the trial course.

Cross-Section A
A=97,900 Ft.^{2} W=2440'
W/S Bank X=71,920' Y=34,750'
E/N Bank X=74,250' Y=34,020'

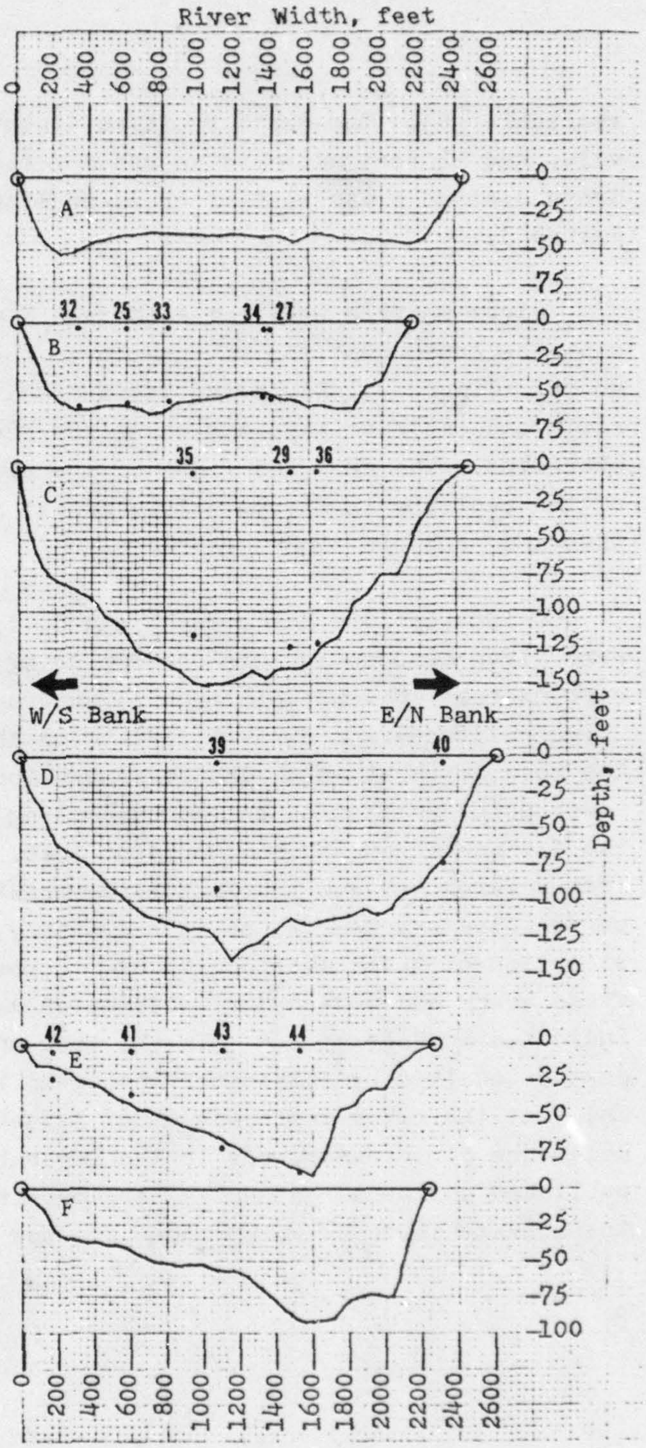
Cross-Section B
A=113,900 Ft.^{2} W=2150'
W/S Bank X=73,150' Y=37,500'
E/N Bank X=75,150' Y=36,700'

Cross-Section C
A=251,600 Ft.^{2} W=2470'
W/S Bank X=73,450' Y=39,800'
E/N Bank X=75,900' Y=40,100'

Cross-Section D
A=244,000 Ft.^{2} W=2620'
W/S Bank X=72,750' Y=40,620'
E/N Bank X=74,960' Y=42,020'

Cross-Section E
A=103,100 Ft.^{2} W=2280'
W/S Bank X=70,780' Y=41,420'
E/N Bank X=71,680' Y=43,520'

Cross-Section F
A=121,200 Ft.^{2} W=2240'
W/S Bank X=68,420' Y=41,620'
E/N Bank X=68,580' Y=43,860'



A = Area W = Width

Figure 3.1 River Cross-Sections

Cross-Section G
A=122,000 Ft.^{2} W=2590'
W/S Bank X=65,420' Y=41,750'
E/N Bank X=65,500' Y=44,340'

Cross-Section H
A=103,600 Ft.^{2} W=2550'
W/S Bank X=62,880' Y=41,750'
E/N Bank X=62,900' Y=44,300'

Cross-Section I
A=113,200 Ft.^{2} W=2240'
W/S Bank X=60,700' Y=41,840'
E/N Bank X=60,730' Y=44,080'

Cross-Section J
A=119,400 Ft.^{2} W=2320'
W/S Bank X=58,140' Y=41,940'
E/N Bank X=58,140' Y=44,260'

Cross-Section K
A=105,400 Ft.^{2} W=2580'
W/S Bank X=55,700' Y=41,750'
E/N Bank X=55,670' Y=44,330'

Cross-Section L
A=111,100 Ft.^{2} W=2910'
W/S Bank X=52,960' Y=41,530'
E/N Bank X=53,000' Y=44,440'

Cross-Section M
A=104,900 Ft.^{2} W=3040'
W/S Bank X=51,040' Y=41,620'
E/N Bank X=51,020' Y=44,660'

Cross-Section N
A=113,400 Ft.^{2} W=2980'
W/S Bank X=47,140' Y=41,830'
E/N Bank X=47,220' Y=44,810'

A = Area W = Width

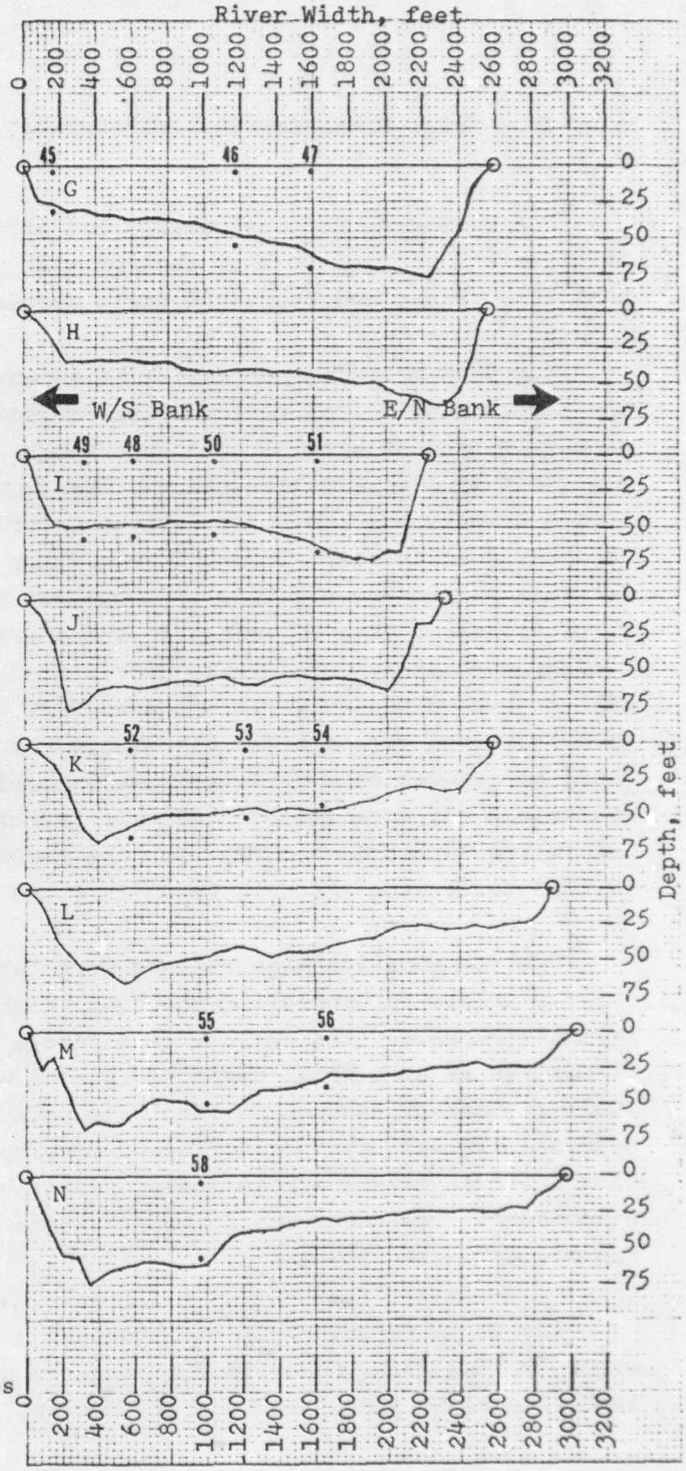


Figure 3.1 River Cross-Sections Continued

IV. TRIAL MEASUREMENTS, INSTRUMENTATION, AND PROCEDURES

The measurements, instruments and procedures used during the tow trials are described in this section with primary emphasis on tow position, rudder and shaft RPM angle measurements directed by RMSA.

Horsepower and propeller RPM measurements were obtained during the tests using Maihak torsionmeter equipment. The horsepower measurements were obtained from strain gauges connected to each propeller shaft aft of the reduction gears. These gauges, which provided shaft torque measurements, were calibrated prior to and during the trials for each shaft at the zero-load point. During the trials, torque readings for each shaft were obtained at about two minute intervals with the revolutions and time of each torque measurements noted. When a torque reading was taken, this event was recorded on the Datalogger used by RMSA to record rudder angle and shaft RPM values. Measurements for each trial run were started and stopped on signal from the pilothouse. These horsepower data were separately compiled and analyzed after the trials and furnished to RMSA for inclusion in the data base. The values furnished to RMSA for the EXXON NASHVILLE and EXXON LAKE CHARLES tests were shown in Appendix C and Appendix D, respectively.

Fuel consumption measurements were taken by Exxon personnel during the trials by connecting the fuel intake lines of each engine to separate barrels. The fuel in each barrel was weighed at the start and completion of each trial segment with the weight difference being the fuel consumed by each engine over the measured time interval. The fuel consumed divided by the total power developed by each engine over the time interval gave specific fuel consumption in pounds per shaft horsepower-hour. Fuel consumption measurements obtained during each trial run are given in Appendix E.

The tow's position and attitude along the test course were measured by RMSA using Motorola Miniranger equipment placed on the towboat pilothouse and on the bow of the tow. RMSA also recorded steering

and flanking rudder movements, port and starboard shaft RPM measurements, and the points in time when test personnel obtained shaft and horsepower measurements. Figure 4.a gives an overview of the physical arrangement of personnel and instrumentation aboard the tow to measure and record tow performance during the trials.

Figure 4.a shows the four principal test and instrumentation stations on the tow--pilothouse, engineroom, steering engineroom, and bow. Test personnel at a station, such as the pilothouse engineroom, maintained communication between themselves during the tests to make sure that events and performance measurements were properly recorded. Inter-station communications between test personnel in the pilothouse and engineroom were maintained via a separate telephone line installed prior to the trials. Communication between RMSA personnel at the bow and pilothouse was maintained by radio.

Sensors connected to the steering and flanking rudder systems and to the port and starboard shafts transmitted voltages continuously by cable to the Datalogger in the pilothouse. Also, RMSA furnished the Exxon contractor with a switch connected to the pilothouse Datalogger which was used during the trials to record the discrete points in time when port and starboard shaft torque measurements were taken. This procedure provided RMSA with a means of correlating separate engine readings with the measurements after the trials.

4.1 Rudder Angle Measurement

Steering activity was measured by recording the movements of the steering and flanking rudders during the trials. Because the port and starboard steering rudders were each mechanically connected in parallel, it was only necessary to measure rudder movement on one side of the rudder system. The rudder angle measurement arrangement shown in Figure 4.b was used to record voltage variations induced by a potentiometer connected to the steering and flanking rudder systems.

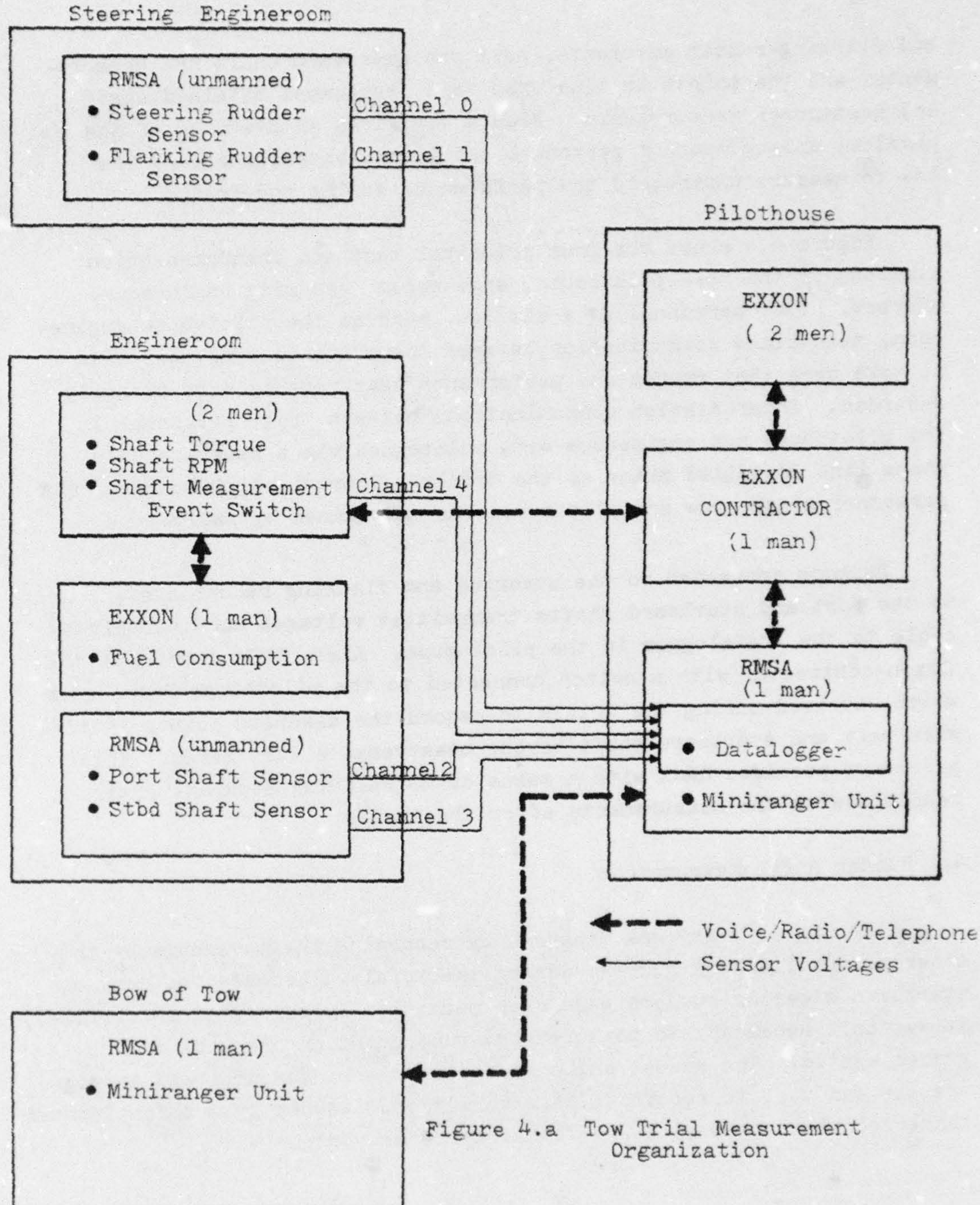


Figure 4.a Tow Trial Measurement Organization

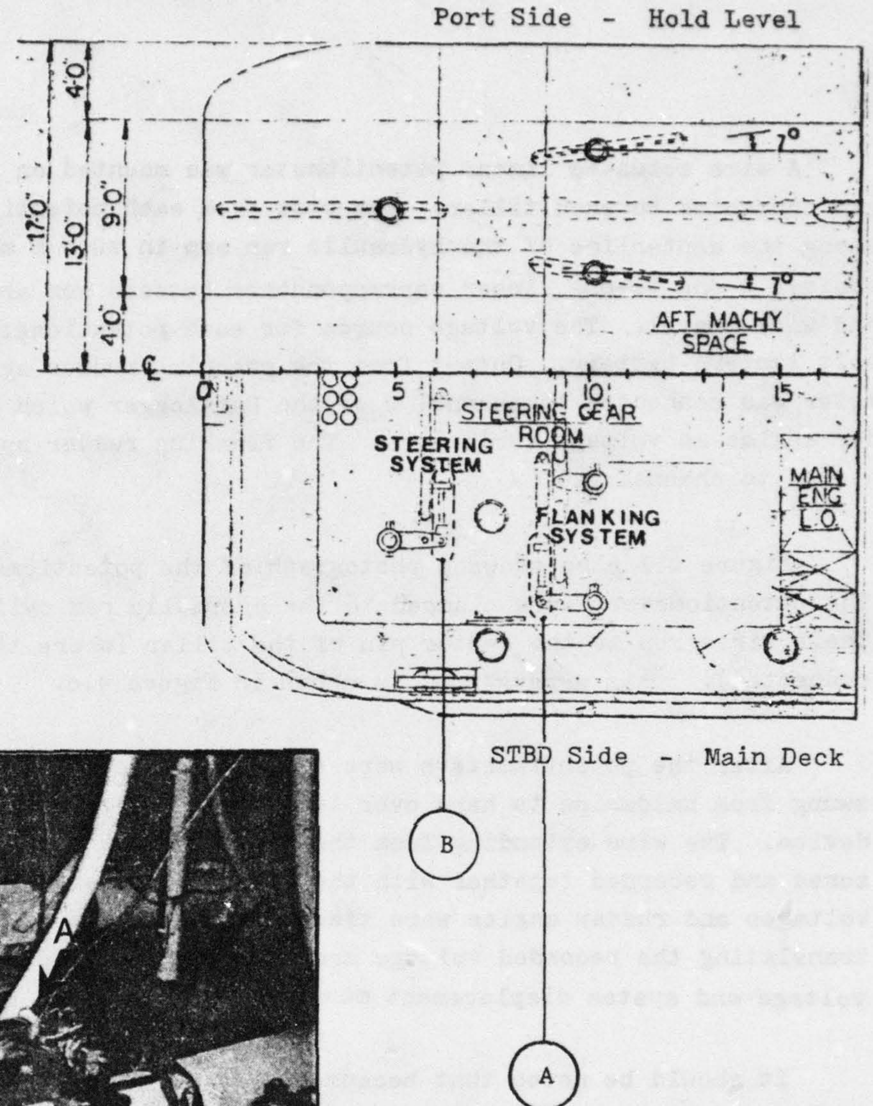
A wire actuated linear potentiometer was mounted on the hydraulic ram connected to each tiller. The wire from each potentiometer was run along the centerline of the hydraulic ram arm in such a manner as to achieve a one-to-one linear correspondence between ram arm extension and wire travel. The voltage source for each potentiometer was a six-volt lantern battery. Output from the steering rudder system potentiometer was connected to channel 0 of the Datalogger which recorded rudder angles as voltage variations. The flanking rudder system was connected to channel 1.

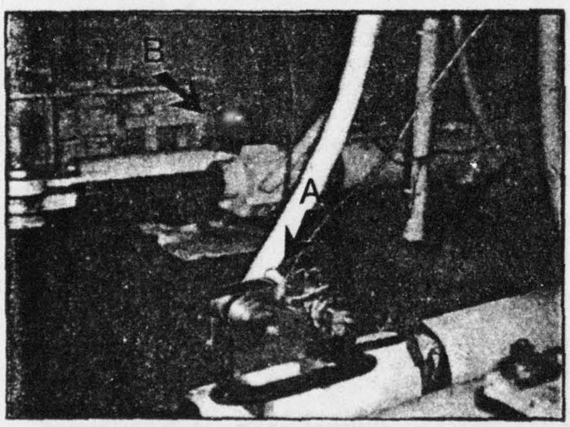
Figure 4.b also shows a photograph of the potentiometer assemblies. The potentiometers were clamped to the hydraulic ram cylinders and their wires run to the center pin of the tiller (where tiller and ram connected). This arrangement is shown in Figure 4.c.

After the potentiometers were connected, each of the rudders was swung from amidships to hard over in each direction to calibrate the device. The wire extending from the potentiometer mounting was measured and recorded together with the observed voltage. These calibration voltages and rudder angles were then used to develop equations for translating the recorded voltage measurements into rudder angles. These voltage and system displacement measurements are given in Table 4.A.

It should be noted that because there are two flanking rudders forward of each propeller, the flanking rudder angle is taken as the "average" angle obtained by both. This can be understood by examining Figure 4.b in which the flanking rudders are shown towed-in toward the propeller by 7 degrees. When the flanking rudders are amidship, then each set of rudders is inclined at an opposing 7 degree angle.

The cosine formula for oblique triangles ($a^2=b^2+c^2-2bc\cos A$) was used to translate rudder system voltages into the degrees of rudder angle used (positive to port for both systems).

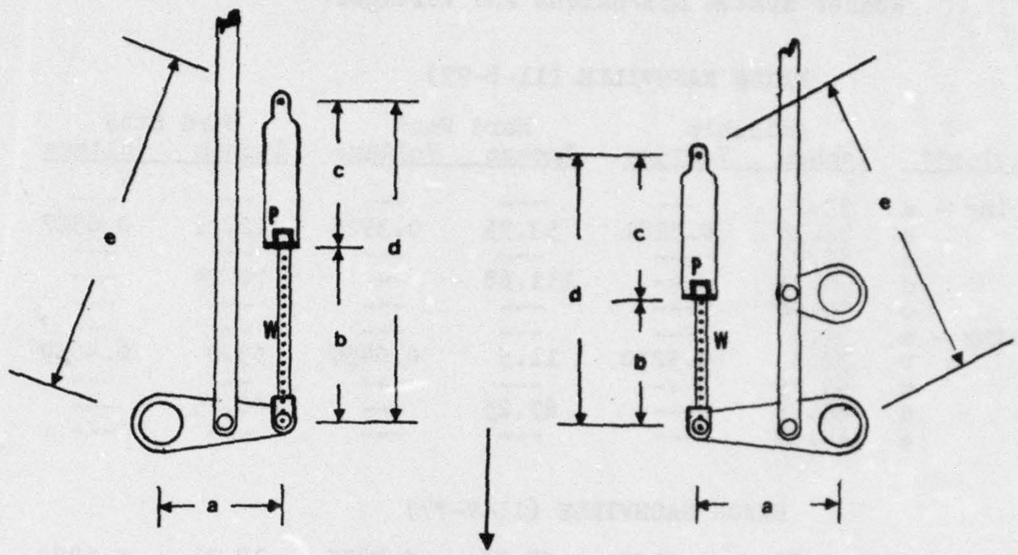




Potentiometer Mountings
(A) Flanking Rudder Potentiometer Apparatus - foreground
(B) Steering Rudder Apparatus - behind

Figure 4.b Rudder Angle Measurement Arrangement

Steering Rudder System Flanking Rudder System



P = Potentiometer Mounting W = Wire from potentiometer to center pin (dotted line)

Dimensions and measured voltages are given in Table 4.A

Figure 4.c Plan View of Rudder Angle Measurement Arrangement

This cosine formula was modified by substituting the appropriate steering system dimensions and then normalizing the equation for voltage rather than length. Because of the current drain on the storage batteries to translate voltages to angles, the resulting equations given at the bottom of Table 4.A were adjusted to reflect a voltage reduction.

4.2 Shaft RPM Measurements

Shaft RPM's were obtained by recording the DC voltages taken from the tachometer generators installed on each shaft of the EXXON NASHVILLE

Table 4.A

Rudder System Dimensions and Voltages*

EXXON NASHVILLE (11-8-77)

Dimension**		Amidship Inches	Amidship Voltage	Hard Port Inches	Hard Port Voltage	Hard Stbd Inches	Hard Stbd Voltage
Steering -	a	32.5	---	---	---	---	---
"	b	32.38	0.5181	53.75	0.3928	12.31	0.6327
"	c	57.93	---	---	---	---	---
"	d	90.31	---	111.68	---	70.24	---
"	e	95.98	---	---	---	---	---
Flanking -	a	32.5	---	---	---	---	---
"	b	32.5	0.5230	11.5	0.6430	53.0	0.4059
"	c	55.75	---	---	---	---	---
"	d	88.25	---	67.25	---	108.75	---
"	e	94.04	---	---	---	---	---

EXXON NASHVILLE (11-9-77)

Steering -	b	32.38	0.5120	53.75	0.3895	12.31	0.6278
Flanking -	b	32.5	0.5131	11.5	0.6381	53.0	0.4029

EXXON LAKE CHARLES (11-10-77)

Steering -	b	41.56	0.4655	61.62	0.3505	21.5	0.5810
"	c	48.75	---	---	---	---	---
"	d	90.31	---	110.37	---	70.25	---
Flanking -	b	38.75	0.4878	19.5	0.5968	59.38	0.3713
"	c	49.5	---	---	---	---	---
"	d	88.25	---	69.0	---	108.88	---

Rudder Angle, $\delta = \pm \theta \mp \cos^{-1}(A+BV+CV^2)$, V = Voltage

Towboat	Date	Rudder	θ, Degrees	A	B	C
Nashville	11-8-77	S	-69.88	-3.5246	9.9437	-4.7808
"	"	F	69.79	-3.6685	10.2962	-5.0117
"	11-9-77	S	-70.28	-3.5124	10.0010	-4.8474
"	"	F	71.02	-3.6448	10.3450	-5.0822
Lake Charles	11-10-77	S	-70.25	-3.0608	9.5616	-4.8559
" "	"	F	69.81	-3.3638	10.0992	-5.1166

*Dimensions a, c, and d when amidships are the same for both towboats.
**See Figure 4.c for meaning of letter designations.

and EXXON LAKE CHARLES. These tachometers developed a linear DC voltage at the rate of 0.6 volt per 100 shaft RPM's. Separate cables were connected to the output terminals of the port and starboard generators. Each of these cables were in turn connected to a channel of the Datalogger -- channel 2 for the port shaft and channel 3 starboard shaft. The tachometer generator polarity was set so that a negative voltage would be generated when the engines were running astern.

Figure 4.d is a photograph showing the exposed portion of the tachometer extending from the reduction gear housing. The cables from the tachometer to the Datalogger were connected in parallel with the towboat's cables so that the pilothouse gauges would not be impaired.

4.3 Datalogger Voltage Measurements

A Fluke Datalogger [6] was used to record voltages from the sensor/monitoring points shown in Figure 4.a. The Datalogger was a multichannel scanning instrument which could be programmed to record voltage values in a user-programmed sequence.

There were 5 voltages recorded by the Fluke Datalogger from the sensors connected to channels 0 through 4. Channel 0 was used to record voltage variations from the potentiometer mounted on the steering rudder and channel 1 to record the voltage variations from the flanking rudder system. Voltages from the shaft tachometer generators were recorded on channel 2 for the port shaft and channel 3 for the starboard shaft. Channel 4 was reserved for recording voltage pulses initiated by test personnel in the engineroom to correlate their SHP measurements with RMSA recorded data. Test personnel were furnished with a 2 button hand-held switchbox which transmitted a voltage pulse to the datalogger when one of the buttons was depressed. When test personnel measured the torque on the port engine, they depressed the appropriate button and a 3+ volt signal was measured. A 1.5 volt signal was recorded when the starboard shaft measurement button was depressed.

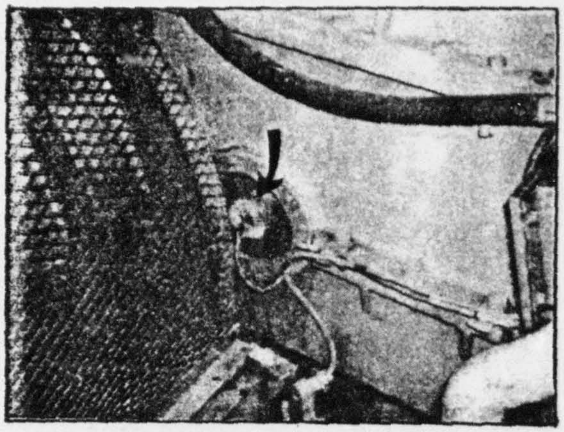


Figure 4.d

Tachometer Installation, Arrow points toward tachometer generator protruding from reduction gear box.

Figure 4.e gives examples of voltages recorded from the 5 channels. The Datalogger was programmed with several alternative channel scanning sequences in an attempt to improve the frequency of data recording. The scheme shown in Figure 4.e appeared to provide the best compromise for recording time and voltage measurements. Except for channel 4, which recorded discrete events, channels 0-3 measured and printed voltages at least 15 times per minute. The first line of print sequence contains the data and time (Date:Hour:Min:Sec) for the voltage from the channel scanned on the following line (Channel Voltage).

For example, Figure 4.e shows that shaft horsepower measurements were taken at 14:21:51 for the port shaft. The RPM voltages recorded on channel 2 for the port engine appeared to be consistantly good while those recorded on channel 3 for the starboard shaft varied considerably. This problem occurred during the first day of the EXXON NASHVILLE tests due to oil leaking into the starboard tachometer generator. This tachometer error on the EXXON NASHVILLE was alleviated when the unit was replaced for the zig-zag tests the next day. The tachometers on the EXXON LAKE CHARLES appeared to perform consistantly.

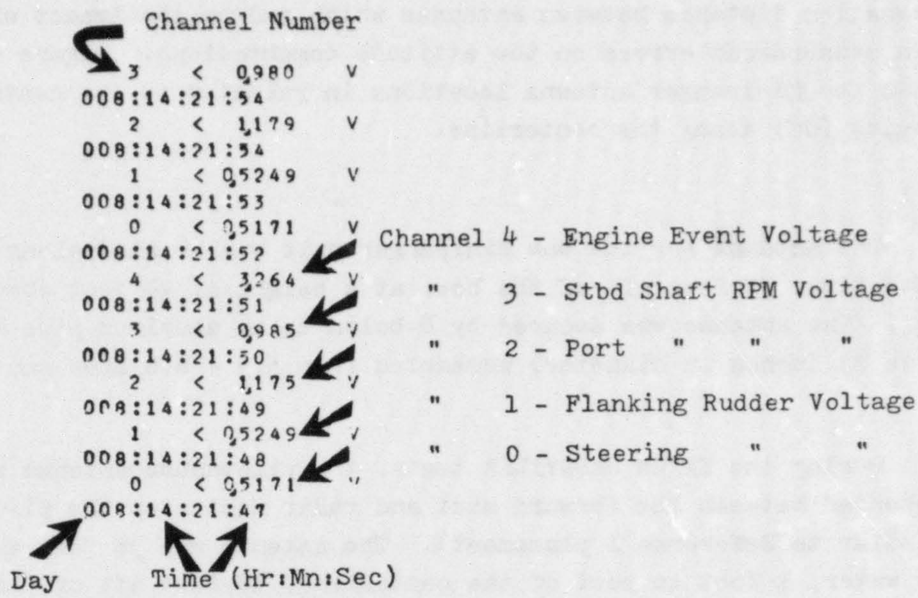


Figure 4.e Datalogger Sample Output

4.4 Tow Position Measurements

Tow positions along the waterway were recorded using two Motorola Miniranger II systems [7]. Each Miniranger system provided fixes by measuring the range in meters between two electronic reference stations (transponders) located ashore and an omnidirectional antenna-receiver unit located on the vehicle. The receivers provided updated range measurements at user selectable time intervals with an accuracy of ± 3 meters (one standard deviation) when the signals formed an angle greater than 30° and less than 150°. A digital printer was attached to the receiver to record time and distances.

Because each antenna-receiver-printer unit recorded its position relative to two known transponder locations, the two units on the tow

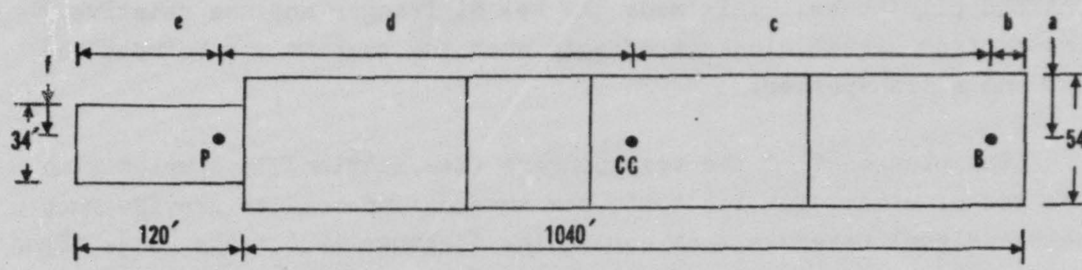
provide simultaneous positions which define the tow's attitude in the waterway. The plan view of the tow shown in Figure 4.f shows the large separation distance between antennas which reduce the impact of position measurement errors on tow attitude computations. Figure 4.f also shows the Miniranger antenna locations in relation to the center of gravity (CG) along the centerline.

The antenna for the bow Miniranger unit was located along the centerline, 35 feet aft of the bow, at a height of 44 feet above the deck. The antenna was secured by U-bolts to an aluminum pipe mast (2 to $2\frac{1}{2}$ inches in diameter) assembled from 5.5 - 6.0 foot sections.

During the EXXON NASHVILLE tests, the pilothouse antenna was suspended between the forward mast and radar mast atop the pilothouse (similar to Reference 1 placement). The antenna was 38 feet above the water, 1 foot to port of the centerline, 28 feet aft of the towboat's bow, and 92 feet forward of the stern. The antenna separation distance was 1033 feet. Locating the antenna in this fashion placed the unit below the radar antenna and relatively clear of adjacent structure.

The position of the antenna on the bow of the tow remained unchanged during the EXXON LAKE CHARLES test. The pilothouse antenna was located on a pipe extension on the towboat's forward light mast. The pilothouse antenna was located along the centerline about 51 feet above the water, 19 feet aft of the towboat's bow, and 101 feet forward of the stern. The separation distance between the bow and pilothouse antennas was 1024 feet.

It should be noted that the EXXON LAKE CHARLES was 8.5 feet higher than the EXXON NASHVILLE. This additional structure height was the reason for the antenna mast on the bow of the tow being an additional 10-12 feet higher than originally planned.



Dimension	EXXON NASHVILLE (Feet)	EXXON LAKE CHARLES (Feet)
a	27	27
b	35	35
c	515.78	515.78
b+c	550.78	550.78
d	517.22	508.22
c+d	1033	1024
e	92	101
f	16	17

P = Pilothouse Antenna B = Bow Antenna CG = Center of Gravity

Figure 4.f Miniranger Antenna and Center of Gravity Relationships

At a height of 44 feet above the deck of the barge, the antenna on the bow was about the same height as the antenna atop the EXXON LAKE CHARLES pilothouse. This made the bow Miniranger antenna relatively immune from signal blockage effects when the towboat was between the bow and a transponder.

The placement of the transponders (See SectionIII) coupled with the use of a mast for the tow's bow antenna appeared to provide much better signal coverage than during the November 1976 tests [1]. Even so, problems were encountered in receiving signals from Transponder 1 by both the bow and pilothouse units when the tow was north of the mid-course range mark--similar to the problems encountered by the bow unit in the 1976 tests. Both bow and pilothouse Miniranger units were affected although the source of the distortion was unknown. The range from Transponder 3 instead of Transponder 1 was used in the northern section of the straight course after it was determined that signals from Transponder 3 could be received well south of the 190 Bridge.

Tow position measurements were recorded at 1 second intervals during critical sections of the test course and at 3-6 second intervals during transition periods when the tow was moving between test areas. Prior to the trials, the bow and pilothouse Miniranger were set to local Baton Rouge time. The time maintained by the Datalogger unit was used as the time base during the trials and the bow and pilothouse Miniranger units were both set to the time given by the pilothouse Miniranger unit.

Figure 4.g was a photograph of the recording instruments located in the pilothouse during the trials. This equipment was located on a utility desk in the after corner of the pilothouse so as to provide minimum interference with navigation. Figure 4.g shows the Miniranger console, printer, Datalogger, and radio unit. Figure 4.h shows the forward end of the lead barge where the bow Miniranger unit was lo-

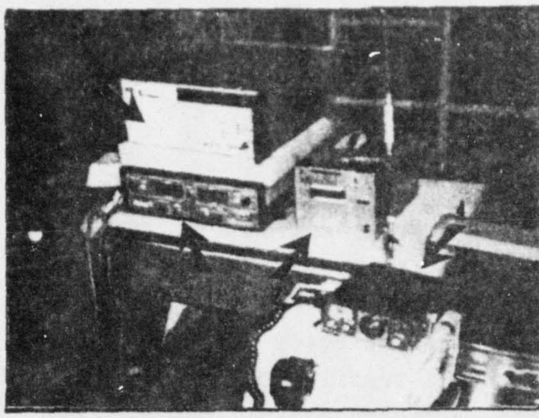


Figure 4.g

Photograph of pilothouse recording apparatus showing Miniranger console (Arrow 1) and printer (Arrow 2), Datalogger (Arrow 3), and radio (Arrow 4).

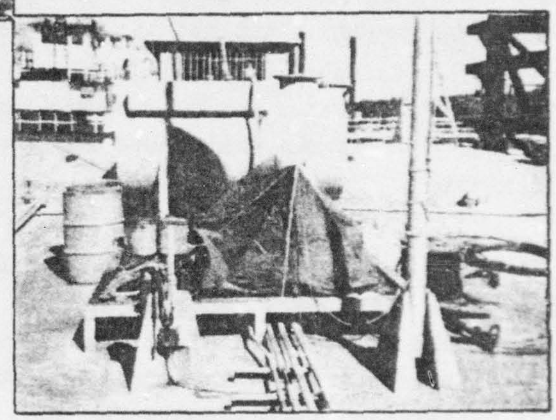


Figure 4.h

Photograph of bow of tow while tied up to the Exxon landing barge. The tent in the forground was used to house the test equipment during trials.

cated. The tent on the bow was used to provide shelter for test equipment and personnel during the trials and became invaluable when the November 8 EXXON NASHVILLE trials encountered heavy rain and the remaining runs were postponed until the following day.

4.5 Trial Procedures

Three upstream and three downstream runs were made during each of the towboat trials in addition to the downstream astern runs as described in Appendix A and Appendix B. The four straight course, speed-power runs over the test course south of the 190 Bridge were conducted to provide independent horsepower measurements over a measured distance. The steering runs were to record tow responses during zig-zag maneuvers and turns around Wilkinson Point bend.

Prior to the trials, members of Exxon's staff and RMSA discussed the tests to familarize towboat and test personnel with the location of the three range marks, approximate test run duration, data recording sequence, time between trial runs required to ready the equipment and turn the tow, and possible navigation and traffic problems. Each trial run sequence was set to begin with an upstream, full-power run over the straight course and continue upstream for a test around the bend. After each run, the tow was turned with the assistance of another towboat and positioned for the next test in the opposite direction.

Prior to each trial run, the bow and pilothouse Miniranger and Datalogger times were recorded so that clock errors between the instruments could be adjusted after the test program. The time required for the tow to transit the straight course was used to establish the time calibration requirements for that run. Exxon and RMSA test personnel each recorded the time abeam the three range marks. When these times were compared later, the Datalogger clock was found to be in error during the EXXON NASHVILLE trials and during the zig-zag tests on the EXXON LAKE CHARLES.

Trial activities were directed from the pilothouse by M. Fedak and Captain Worley of Exxon who worked with the pilots of both towboats in coordinating tow movements. J. McCracken of Exxon was stationed in the engineroom and obtained fuel measurements. R. Schulz of RMSA, stationed in the pilothouse, operated the pilothouse Miniranger and Datalogger and coordinated the activities of B. Schulz of RMSA operating the Miniranger unit on the bow. E. Shearer of Hillman assisted in the pilothouse by timing events and manning the

radar during the trials. The tow's telephone and intercom systems were used to maintain communication between the pilots and crew. A separate telephone line was installed to communicate between pilothouse and engineroom and RMSA used radios to communicate between pilothouse and bow.

V. EXXON NASHVILLE STEERING TESTS

This section of the report contains figures and plots of the steering tests performed on the EXXON NASHVILLE. Because of the voluminous data obtained during the trials, primary emphasis was placed on showing the physical location of the tow in the waterway over time in conjuction with plots of key performance parameters typically used to describe a tow's characteristics - - speed (U), shaft horsepower (SHP), and propeller speed (RPM). The more dynamic variables such as drift angle (β), yaw rate ($\dot{\psi}$), and rudder angle (δ) have been plotted as well.

These figures provide graphic evidence of the extent of the data base and should point toward areas where the data should be examined more closely to establish tow behavior parameters. In particular, the figures and graphs establish the link between the charted parameter variation and the prototype environment at the time.

Figure 5.a shows the EXXON NASHVILLE in Wilkinson Point bend. The pilot had attempted to bring the tow along the inside of the bend using a rudder angle of about 15°. The current in mid-channel caught the bow, however, and forced the pilot to apply both hard left rudder and full power to compensate and complete the turn as shown in Figure 5.b. Figure 5.b also shows a speed reduction primarily due to rudder usage in the first part of the turn on the order of 15 percent of the initial speed.

Figure 5.c shows the EXXON NASHVILLE headed downstream for Run 2 around the bend using a constant half power. Throughout these tests, it was made clear to the pilots that the rudder used in the downstream steering maneuver was completely at their discretion. As a result, the amount of rudder used and the method of steering the turn varied considerably between pilots. Run 2 is an example of cutting along the inside of a bend in which the pilot kept the drift angle to a minimum. This turn encountered the eddy current flush on

the bow and showed relatively little sheer but a marked reduction in speed at about 15:42:00 as shown in Figure 5.d.

Figure 5.e shows the tow headed upriver at half power and beginning to make the constant 15° rudder angle turn when it became clear that agreement between the EXXON NASHVILLE and a downbound tow had been misunderstood and the turn had to be aborted. The EXXON NASHVILLE maneuvers plotted show the tow being slowed with full astern and maneuvered clear of the downbound tow in mid-channel. Figure 5.f shows the extreme maneuvers undertaken in which the engines were used in both full ahead and full astern modes, steering and flanking rudders were brought hard over, and the tow assumed a drift angle of 90°. Throughout the maneuvers, the yaw rate was moderate indicating that the tow was well under control.

Figure 5.g shows the EXXON NASHVILLE headed downriver at half power for Run 4. Variable rudder was used as the tow maintained a well-controlled tight turn. The plot of speed and rudder angle in Figure 5.h showed the typical pattern of speed loss due to rudder usage. Moreover, the steering rudder and drift angles appeared very symetric. This type of pattern should be valuable in establishing guidelines for estimating channel widths in bends.

Figure 5.i shows the EXXON NASHVILLE performing the Z maneuver in which relative bearings using the towboat's radar were used to determine when the tow's head had swung an amount equal to the rudder applied. In terms of experimental control, this Zig-Zag test was perhaps as well executed as possible in a waterway environment with the amount of rudder applied being almost the same in each direction. Figure 5.j shows these values plotted in which the gradually increasing RPM and SHP values over the Zig-Zag course kept the tow's speed somewhat higher than might have been expected.

Figure 5.k shows the tow headed upstream at half power for a turn around Wilkinson Point bend. The tow started the constant rudder left turn too far south and had to begin using starboard rudder after 6 minutes to complete the turn. Figure 5.l shows the tow's performance parameters plotted for this turning maneuver. During the time when the rudder was constant at 15° left, speed over the ground continually decreased and the pattern appeared smoother than the variations observed during the other turns.

Figure 5.m shows the last turning maneuver performed in the bend area during the EXXON NASHVILLE trials. This was Run 6, a half-power downstream turn using variable right rudder. Figure 5.n shows the tow still accelerating at the beginning of the turn with tow speed still increasing until almost 20° of right rudder had been applied. Once again the symmetrical complementary nature of the drift angle and rudder angle are shown. The turn was one of the smoother turns completed and provides good insight into speed loss and rudder usage interactions.

Figure 5.o shows the final steering maneuver performed during the EXXON NASHVILLE trials as a full power Zig-Zag maneuver over the straight course. The slightly easterly bias assumed by the tow over the course was due to the pilot's expert planning while approaching the course, so as to perform the Zig-Zag turns as part of evasive maneuvers around other traffic. Figure 5.p shows the variations in the tow's principal performance parameters over the course in which the speed (U) and drift angle (β) show extreme fluctuations during the second rudder deflection probably due to the passing tows.

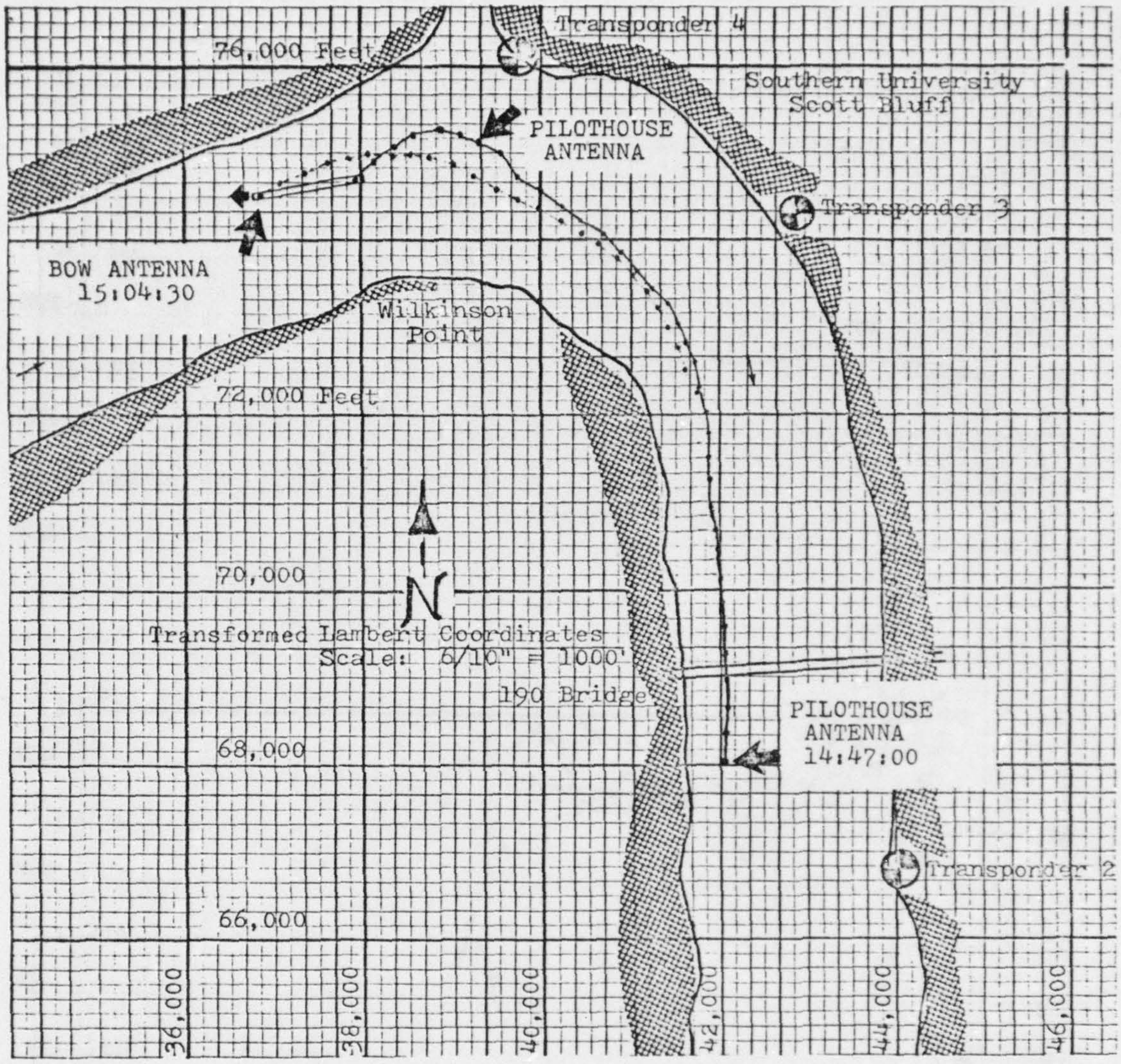


Figure 5.a EXXON NASHVILLE - Upstream Run 1
Half Power Steady Turn in Bend

Notes to Figure 5.a: Points are plotted at 30 second intervals beginning at 14:47:00 for the Pilothouse Antenna and 14:52:30 for the Bow Antenna.

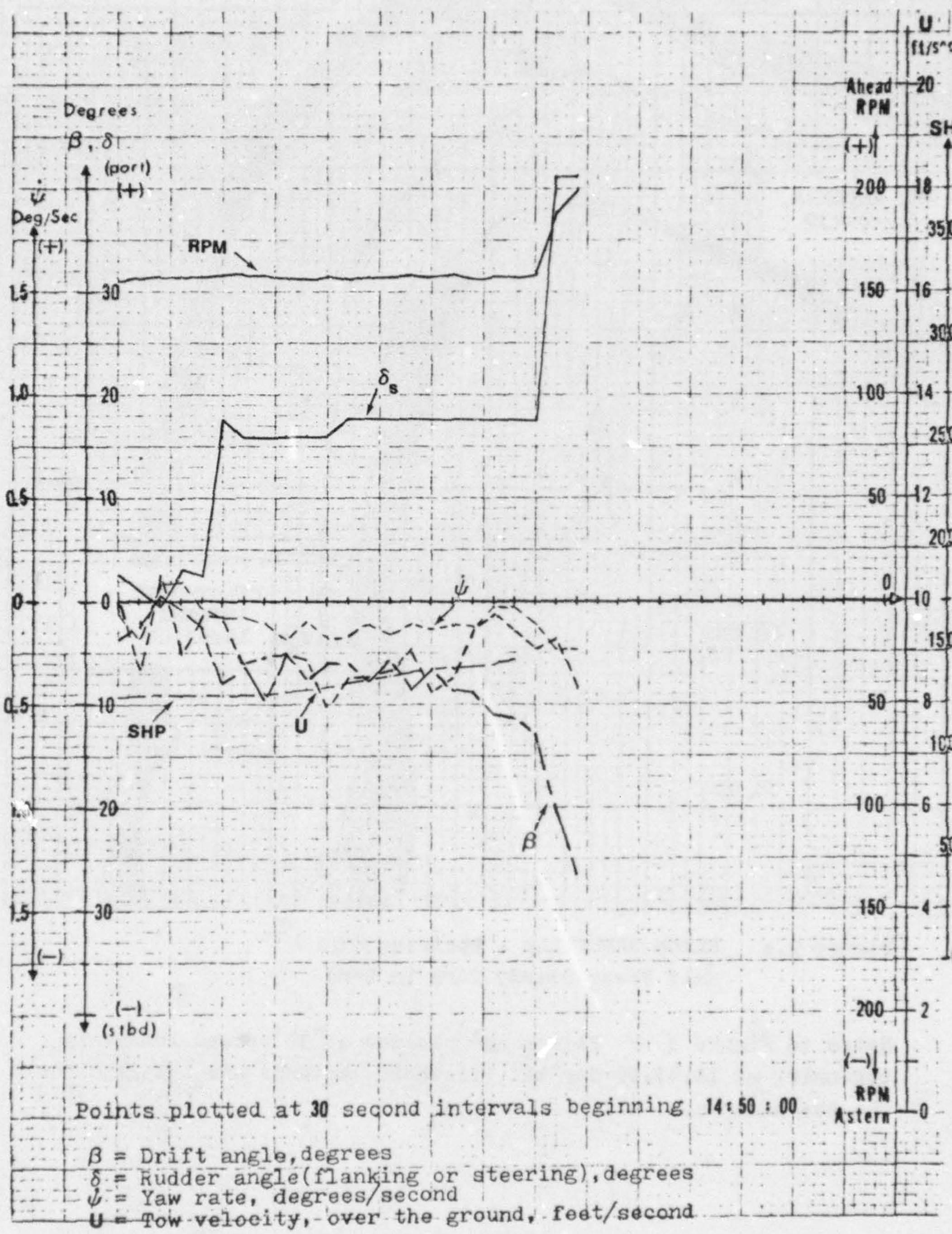


Figure 5.b EXXON NASHVILLE - Upstream Run 1 - Half Power Turn in Bend

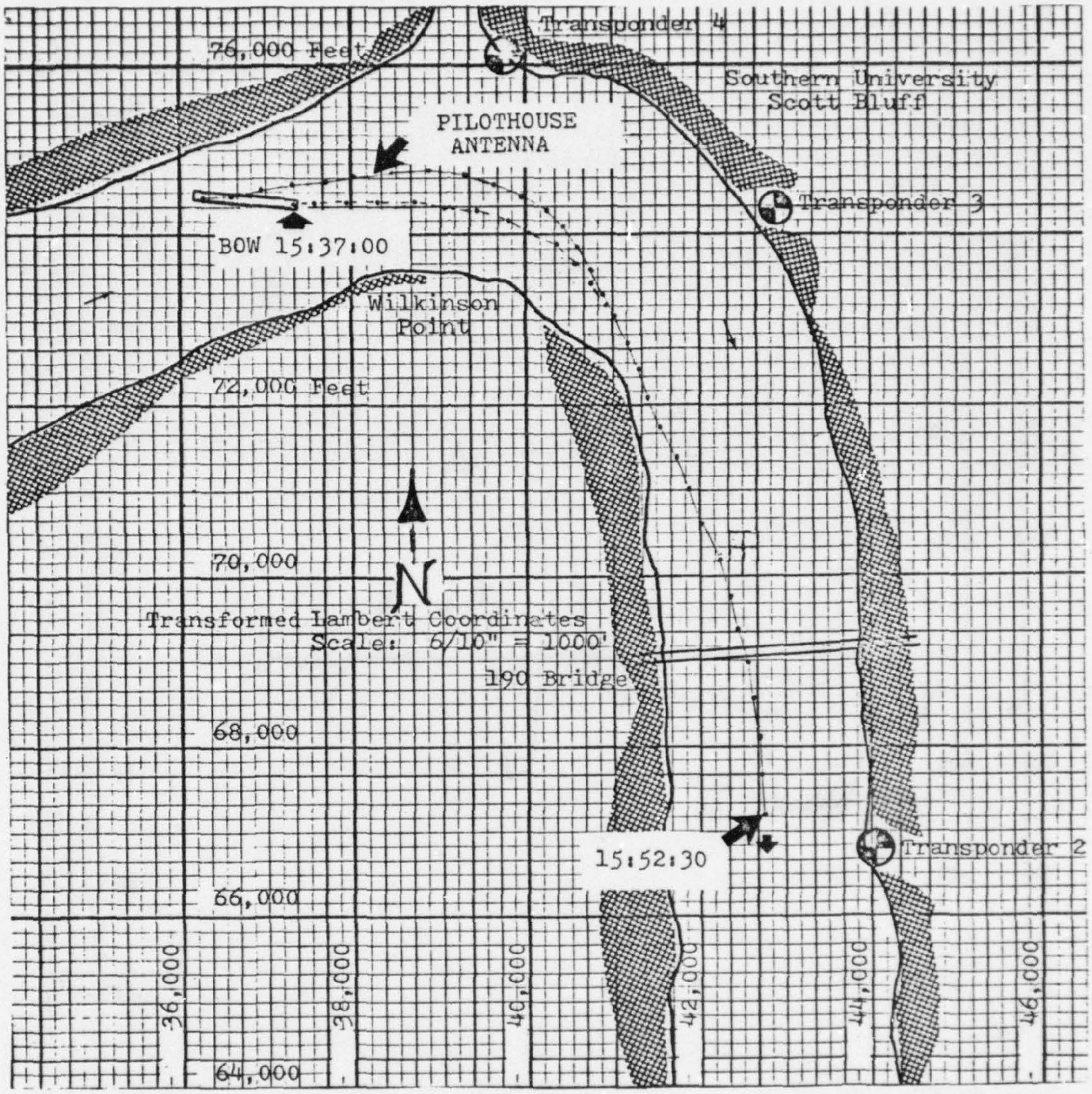
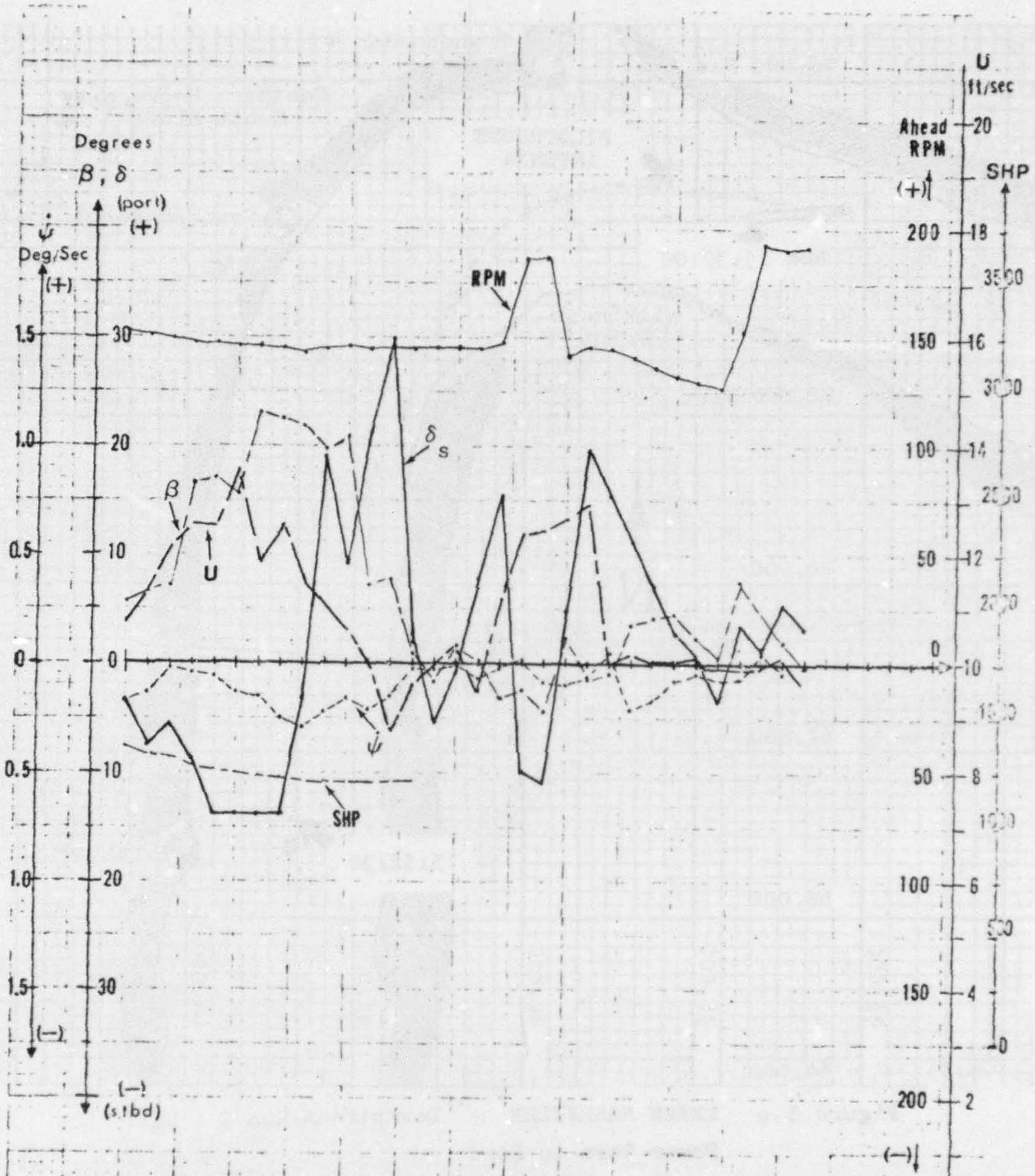


Figure 5.c EXXON NASHVILLE - Downstream Run 2 - Half Power Turn in Bend

Notes to Figure 5.c: Points are plotted at 30 second intervals beginning 15:37:00 and ending at 15:52:30 for the Pilothouse antenna and ending at 15:43:00 for the Bow Antenna.



Points plotted at 30 second intervals beginning 15:37:00

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
$\dot{\psi}$ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 5.d EXXON NASHVILLE - Downstream Run 2 - Half Power Turn in Bend

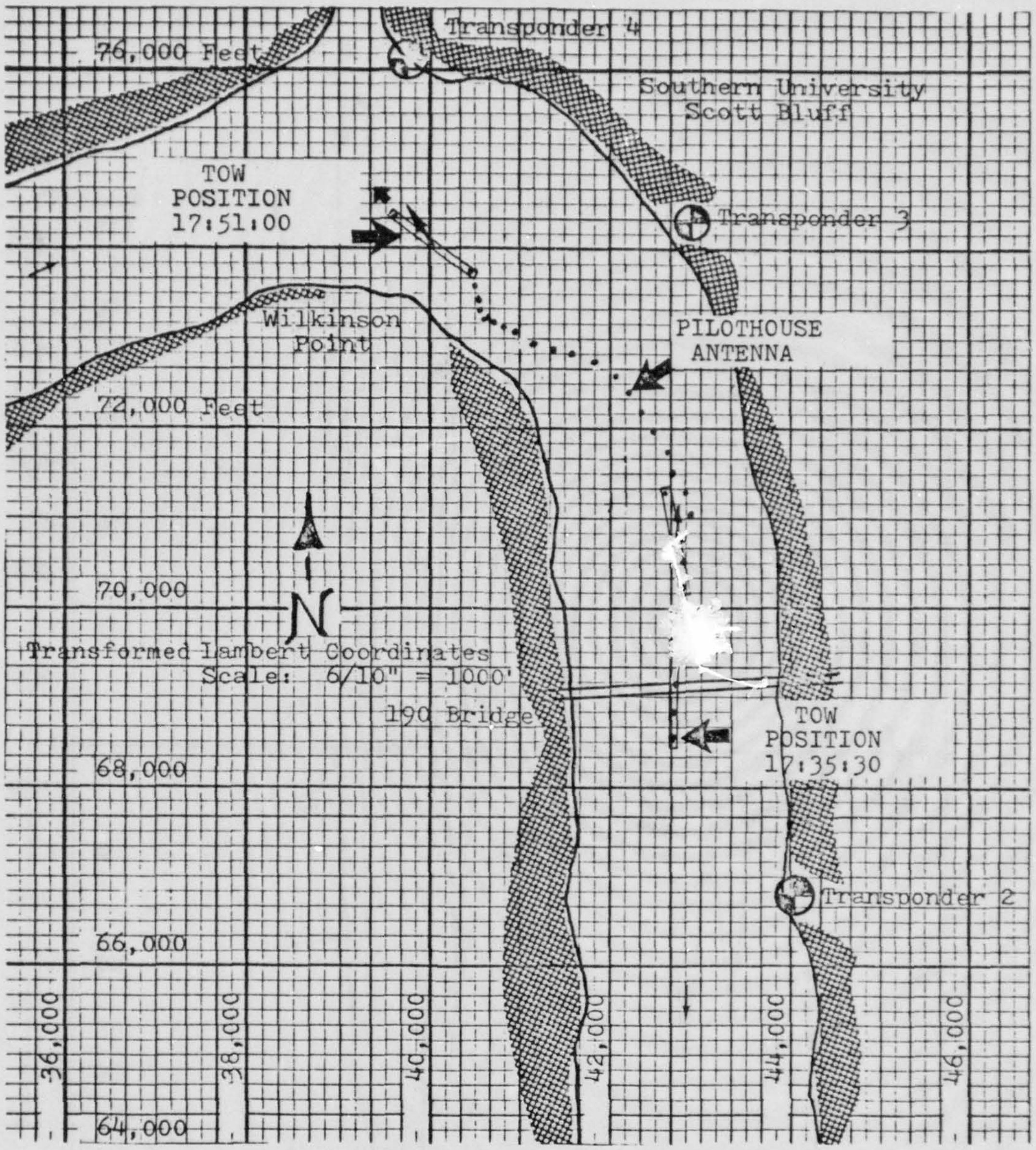
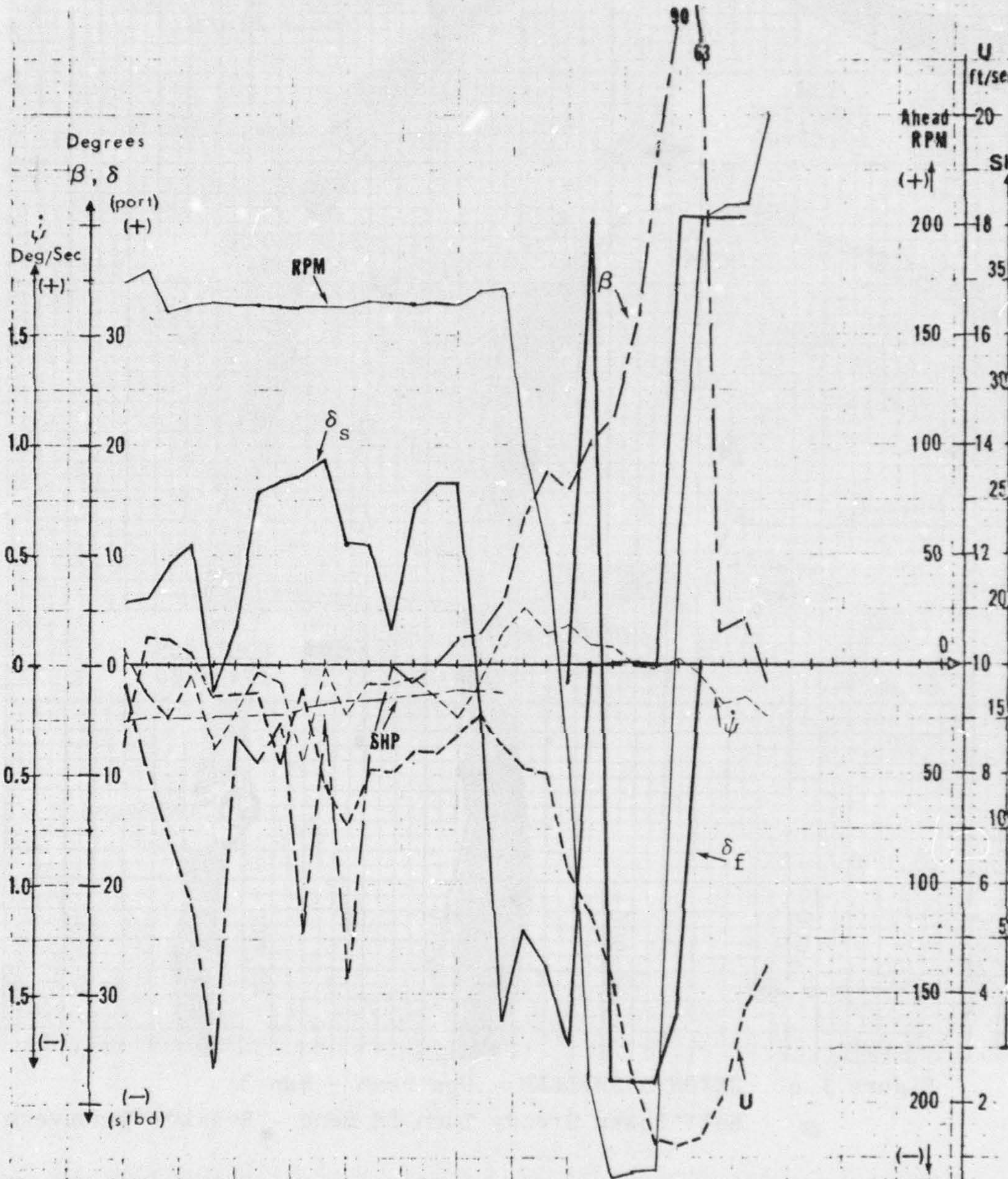


Figure 5.e EXXON NASHVILLE - Upstream - Run 3
Half Power Steady Turn in Bend - Evasive Maneuvers

Notes to Figure 5.e: Pilothouse Antenna positions are plotted at 30 second intervals beginning at 17:35:30. The arrows from the tow indicate the tow's resultant velocity relative to the tow's head. Evasive maneuvers were taken to avoid a downbound tow.



Points plotted at 30second intervals beginning 17:35:30

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
ψ̇ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 5.f EXXON NASHVILLE - Upstream Run 3 - Half Power Steady Turn in Bend - Evasive Maneuvers

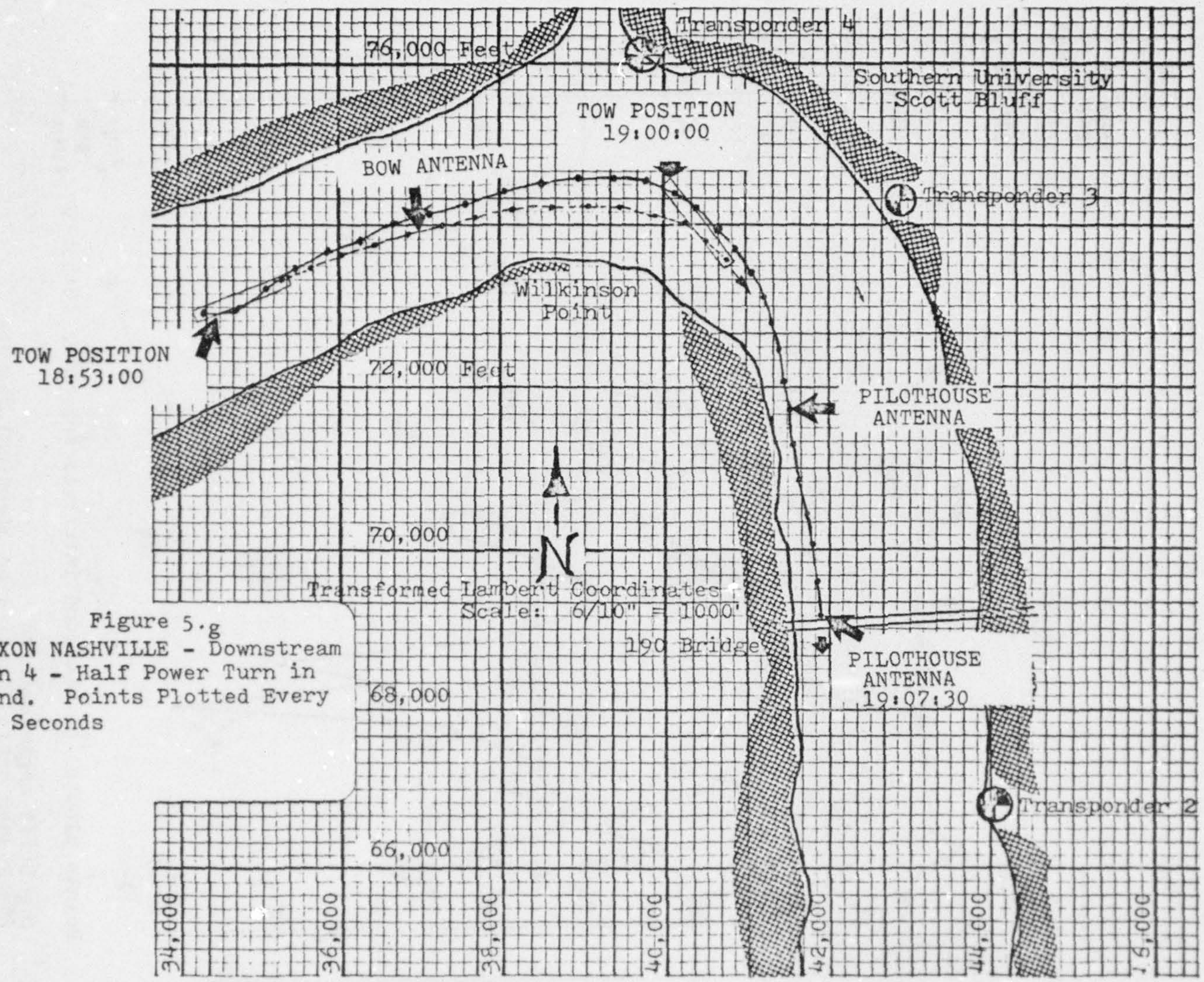


Figure 5.g
EXXON NASHVILLE - Downstream Run 4 - Half Power Turn in Bend. Points Plotted Every 30 Seconds

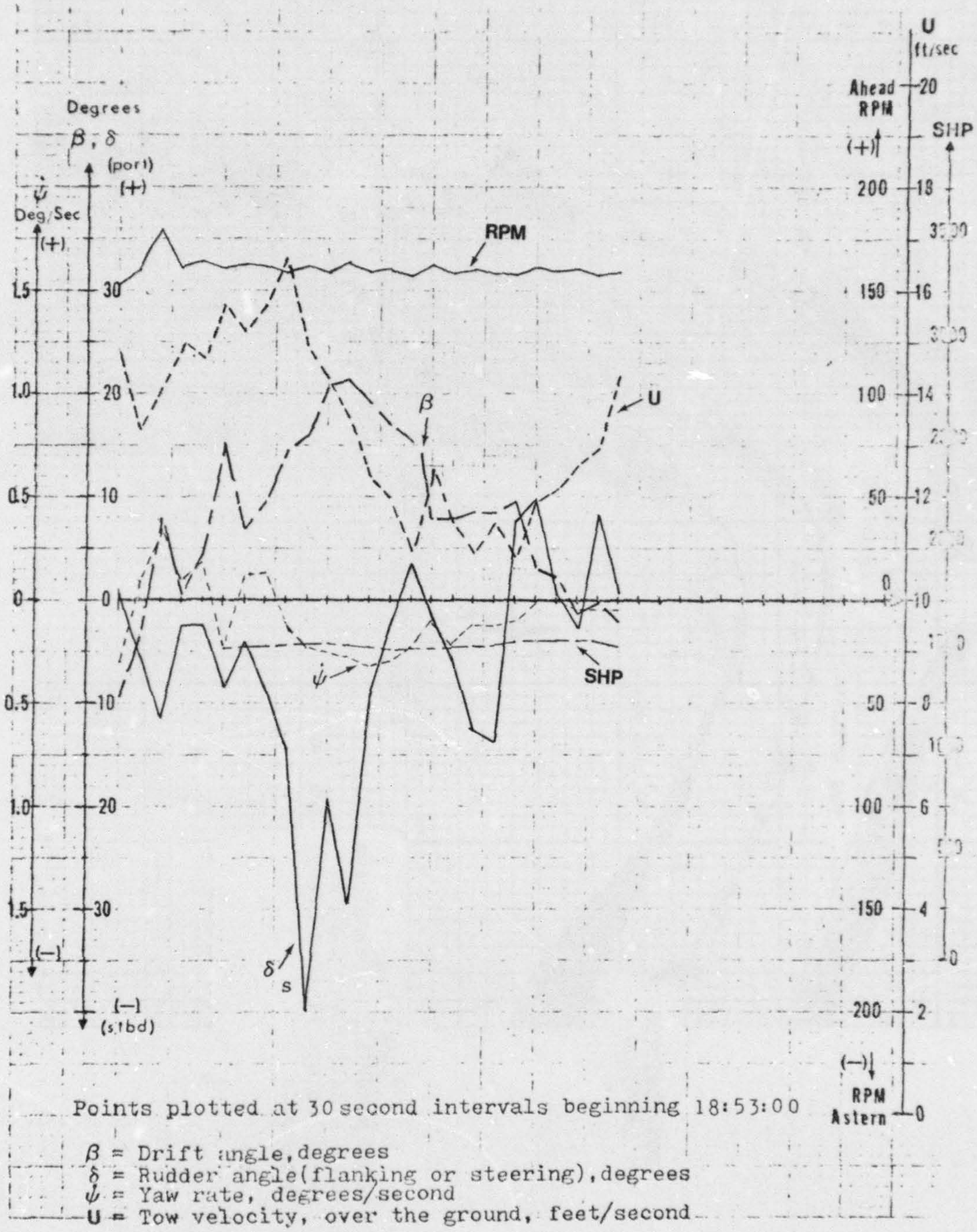
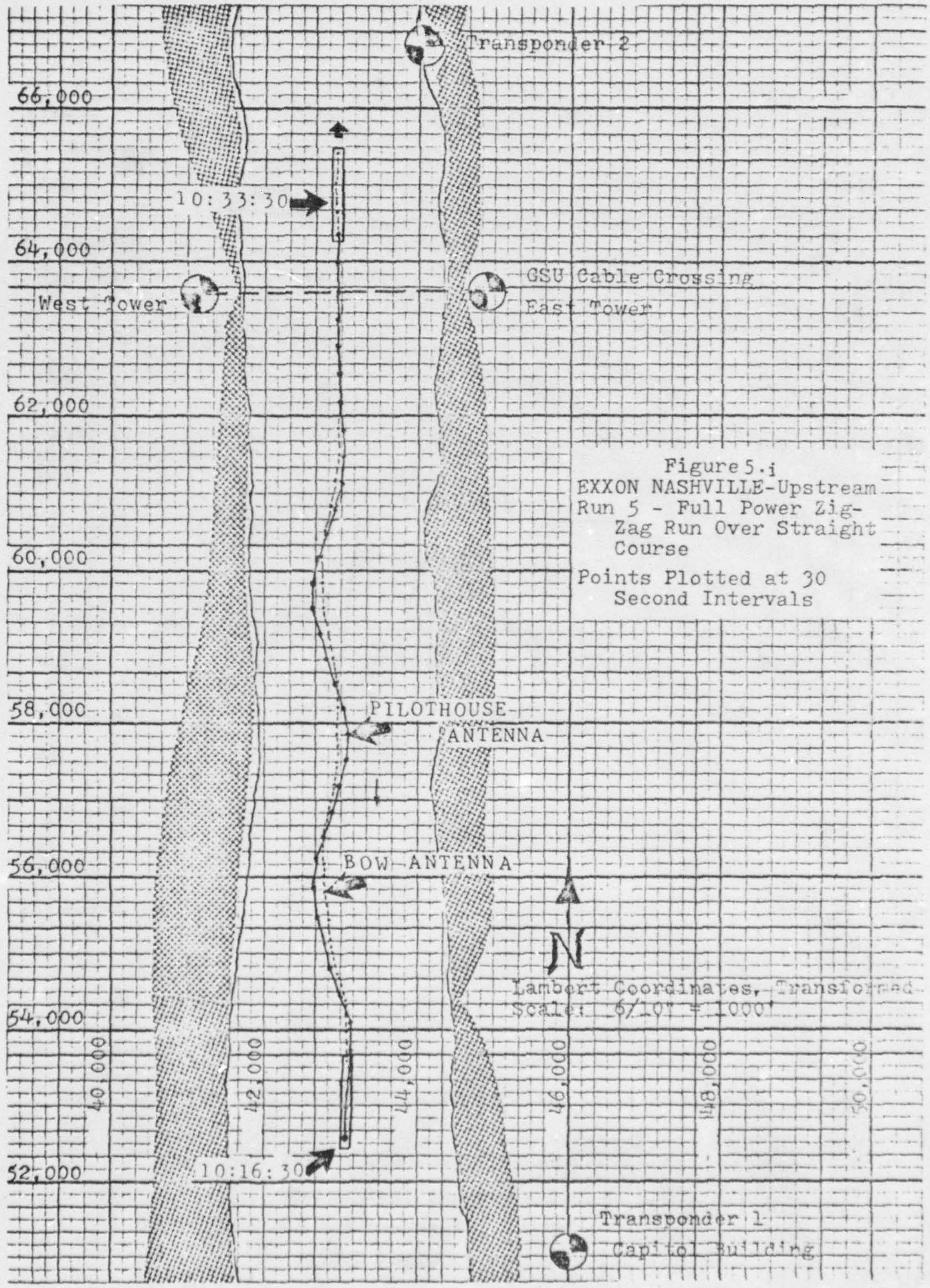
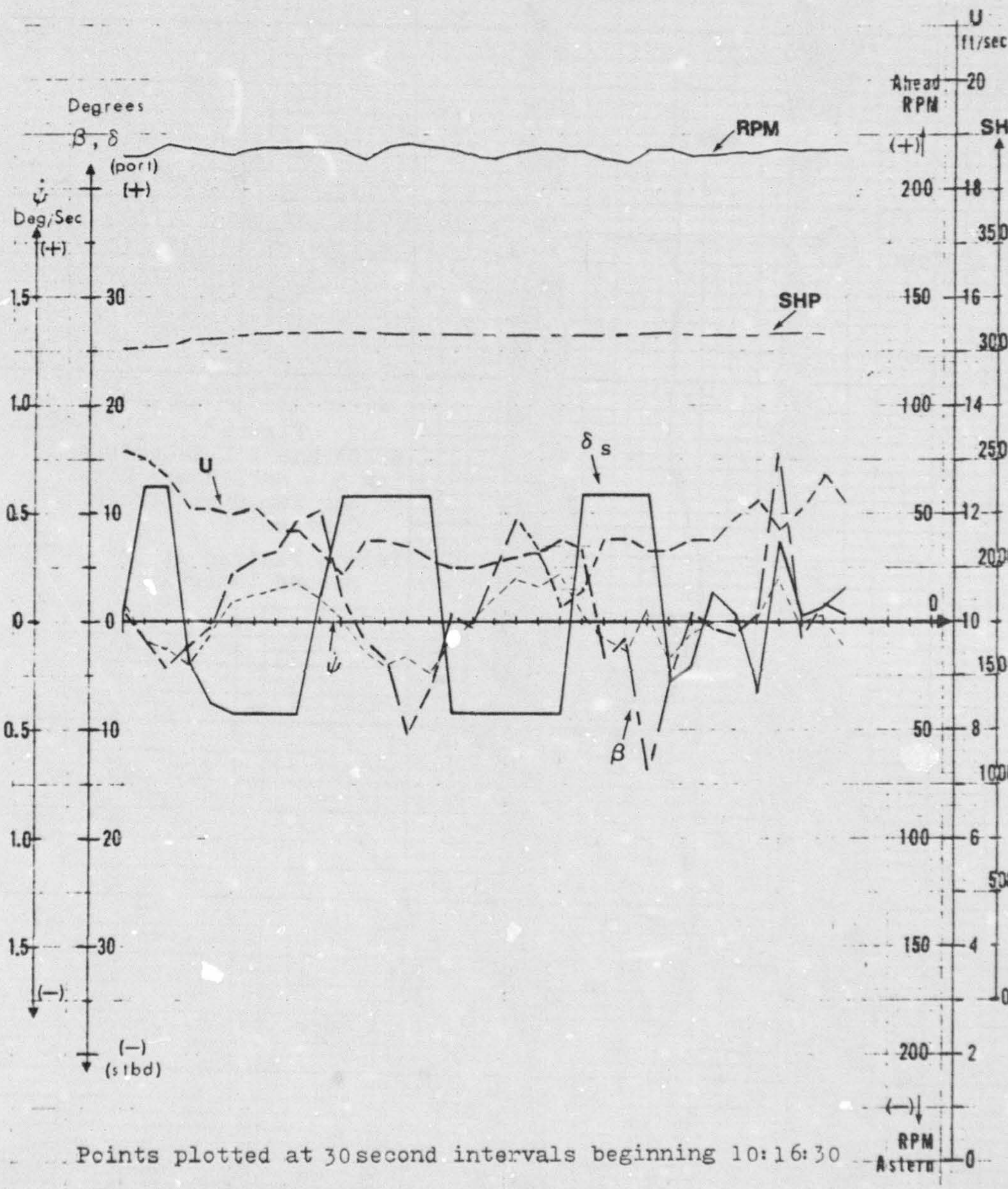


Figure 5.h EXXON NASHVILLE - Downstream Run 4 - Half Power Turn Around Bend


Transponder 2
66,000
10:33:30
64,000
GSU Cable Crossing
West Tower
East Tower
62,000
Figure 5.i
EXXON NASHVILLE-Upstream
Run 5 - Full Power Zig-Zag Run Over Straight Course
Points Plotted at 30 Second Intervals
60,000
58,000
PILOTHOUSE ANTENNA
56,000
BOW ANTENNA
N
Lambert Coordinates, Transformed
Scale: 6/10" = 1000'
54,000
40,000
42,000
44,000
46,000
48,000
50,000
10:16:30
52,000
Transponder 1
Capitol Building



Points plotted at 30 second intervals beginning 10:16:30

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
$\dot{\psi}$ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 5.j EXXON NASHVILLE - Upstream Run 5 - Full Power Zig-Zag Run Over Straight Course

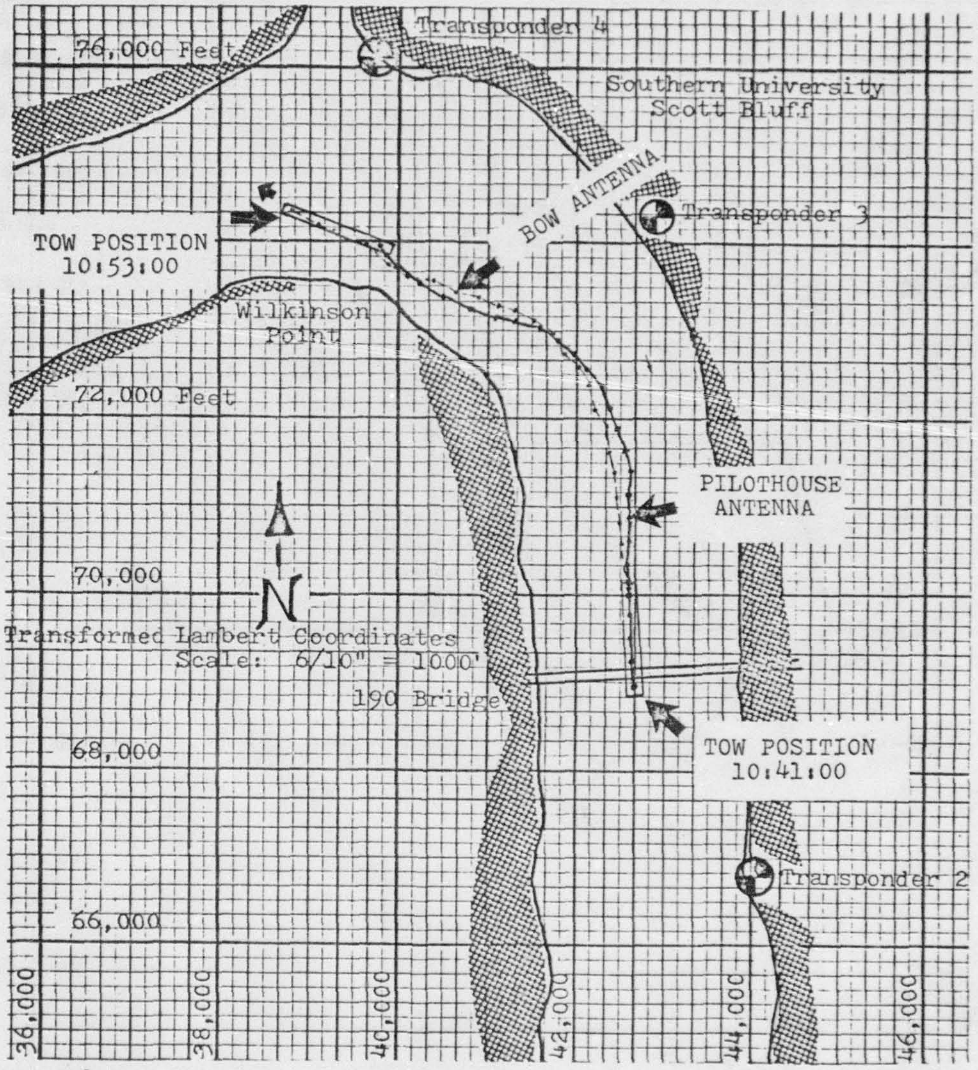
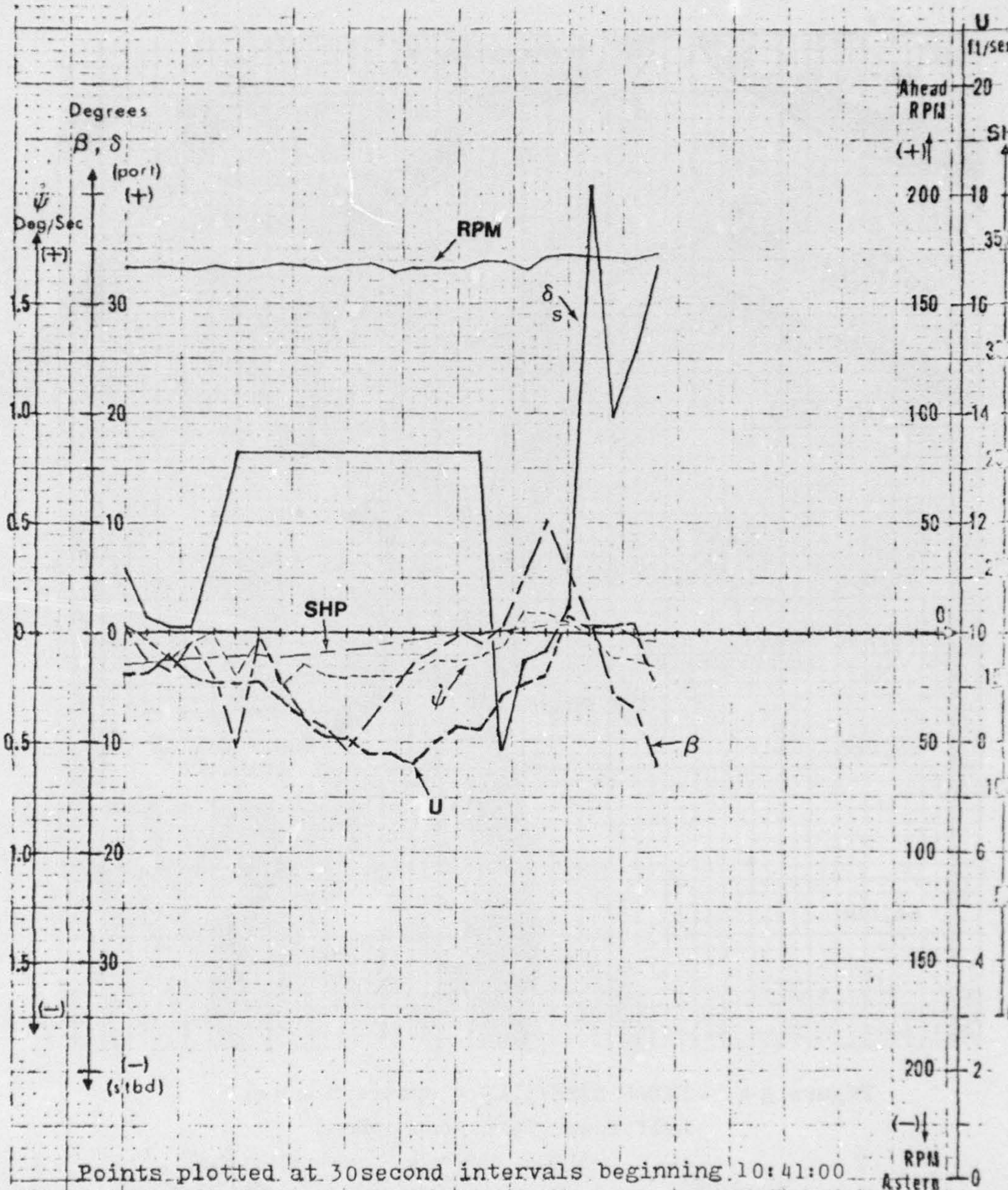


Figure 5.k EXXON NASHVILLE - Upstream - Run 5
Half Power Turn Around Bend

Notes to Figure 5.k: Positions Plotted at 30 second intervals beginning at 10:41:00.



β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
$\dot{\psi}$ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 5.1 EXXON NASHVILLE - Upstream Run 5 - Half Power Constant Rudder Turn in Bend

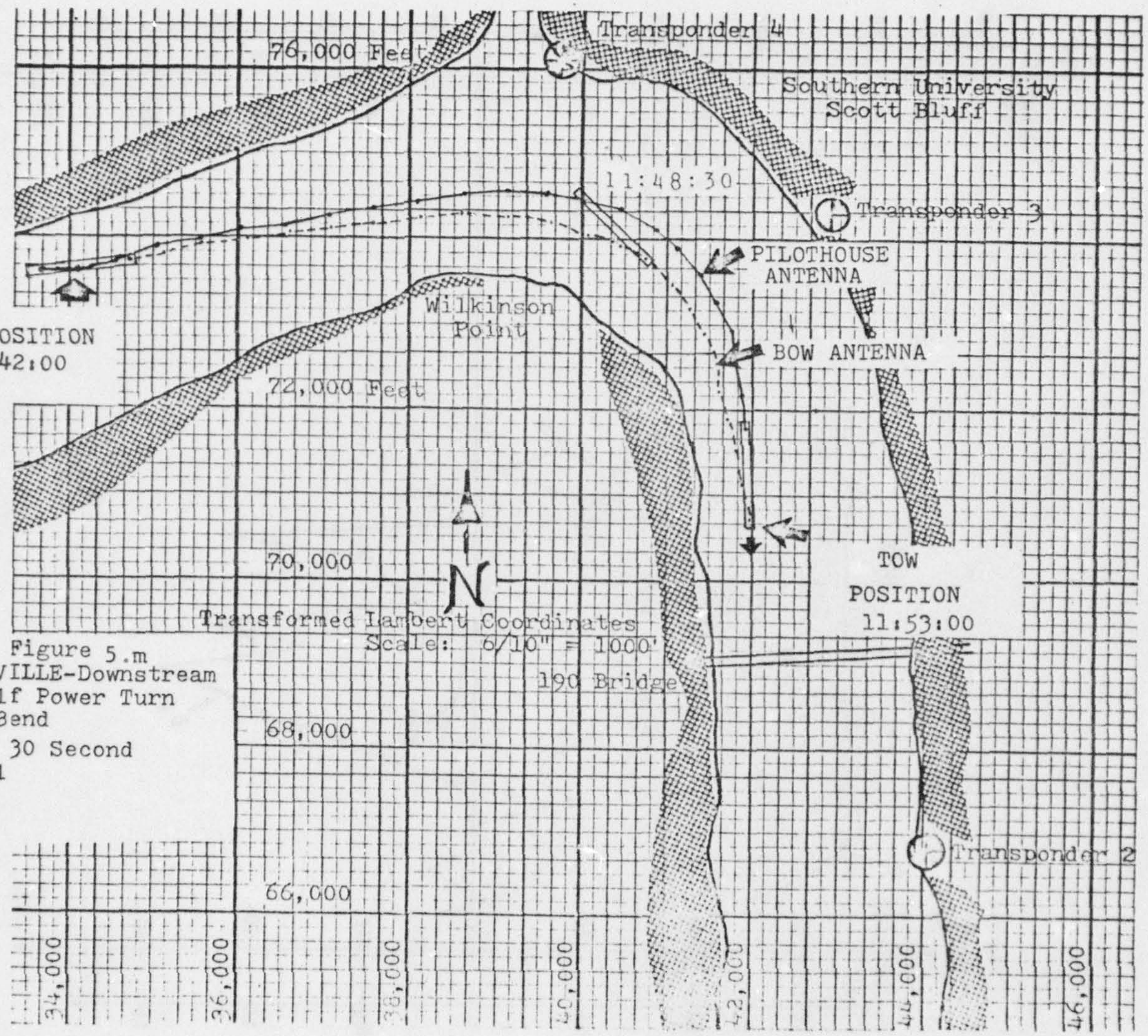
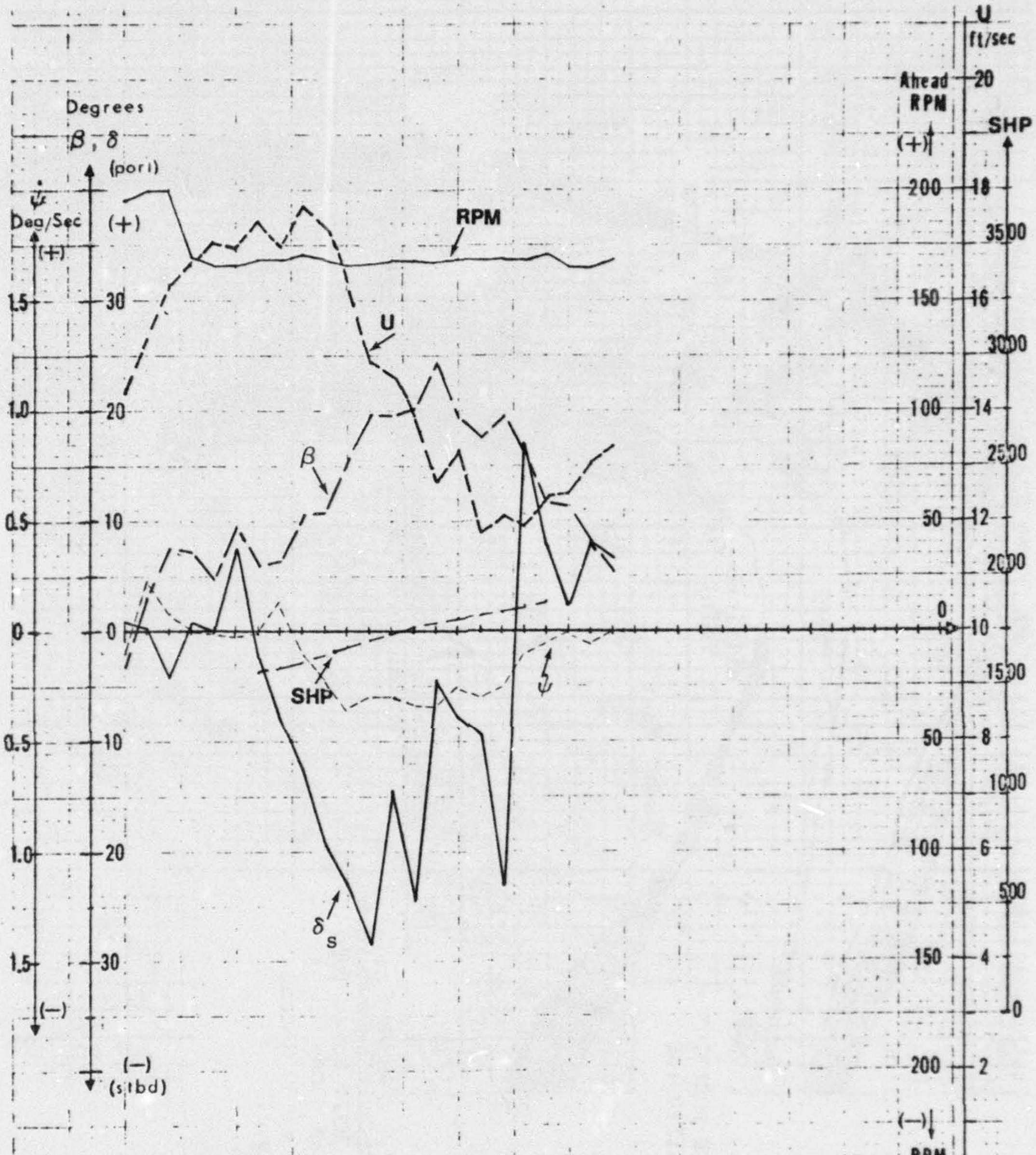


Figure 5.m
EXXON NASHVILLE-Downstream
Run 6 - Half Power Turn
around Bend
Plotted at 30 Second
Interval



Points plotted at 30 second intervals beginning 11:42:00

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
$\dot{\psi}$ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 5.n EXXON NASHVILLE - Downstream Run 6 - Half Power Turn in Bend

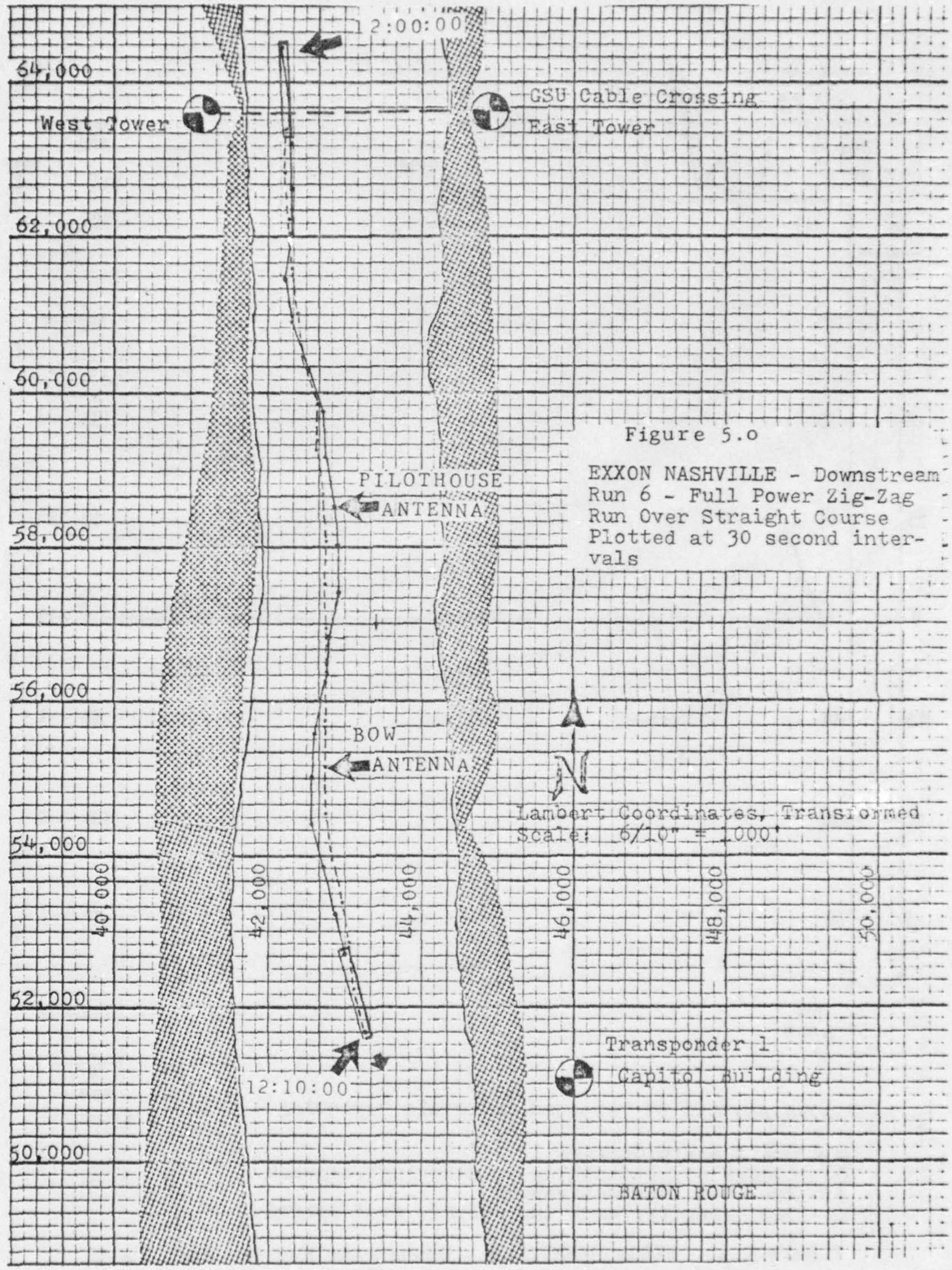
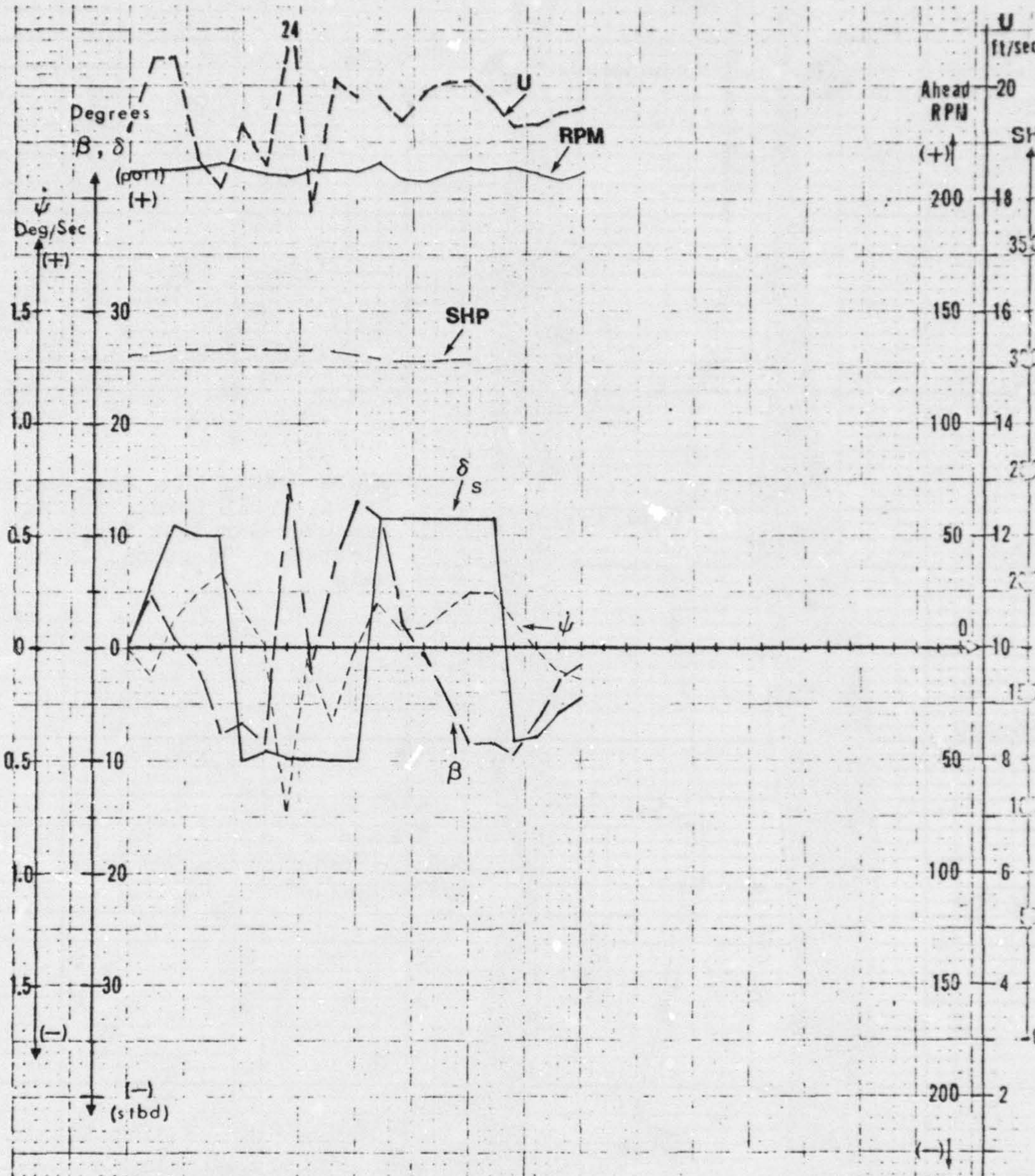


Figure 5.0

EXXON NASHVILLE - Downstream Run 6 - Full Power Zig-Zag Run Over Straight Course Plotted at 30 second intervals



Points plotted at 30 second intervals beginning 12:00:00

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
ψ̇ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 5.p EXXON NASHVILLE - Downstream Run 6 - Full Power Zig-Zag Run Over Straight Course

VI. EXXON LAKE CHARLES STEERING TESTS

This section of the report reviews and describes the steering tests performed on the EXXON LAKE CHARLES in November 1977. The tests were similar to those performed on the EXXON NASHVILLE described in the preceding section of the report. The figures and graphs in this section relate to turning maneuvers performed in the Wilkinson Point bend area and Z maneuvers performed in the straight course area. Because of the large amount of data collected during the tests, this section provides perspective into the physical geography at the time of the tests in relation to the performance parameters plotted on the following pages.

Figure 6.a shows the EXXON LAKE CHARLES headed upriver at half power for a turn around Wilkinson Point bend. The figure shows the long constant rudder turn achieved and marks the first time in any of the Exxon trials that a tow was able to complete a 90° turn without having to adjust the rudder. The key performance data generated during the turn are given in Figure 6.b. These data show the relatively constant yaw rate achieved of 0.2°/ second after the turn had steadied.

Figure 6.c shows the EXXON LAKE CHARLES headed downstream for the Run 2 turn around Wilkinson Point bend. This plot of the tow's track during the turn is instructive because it clearly shows the impact of eddy currents on turning behavior. At 24:01:00 the bow of the tow is shown being set toward the bank. This current set conforms to the current data given in Section 3.3. Figure 6.d shows the tow's parameters during the turn in which tow speed slowed from over 14 feet/ second to 10 feet/second due to rudder and eddy current effects.

Figure 6.e shows the EXXON LAKE CHARLES making the upstream constant rudder turn at 3/4 power during Run 3. This run was performed at 3/4 power to provide more of a direct comparison between the higher powered EXXON MEMPHIS and EXXON NASHVILLE test results. Over 90° of the constant rudder turn was completed before rudder settings were

changed. Figure 6.f shows the tow's performance parameters during the turn. The relatively constant yaw rate during the first 8 minutes of the turn changed as the bow of the tow was influenced by outflow from the channel to the north.

Figure 6.g shows the last bend turning maneuver performed during the EXXON LAKE CHARLES tests. The figure shows the tow following the inside of the bend during the turn with the tow's attitude such that the eddy slowed the tow but caused little sheering. Figure 6.h shows the tow's turning parameters plotted in which the tow's speed is shown falling from 16 feet/second to 10 feet/second due to the eddy current and to the large rudder angle employed.

Figure 6.i shows the EXXON LAKE CHARLES Run 5 upstream Z maneuver plotted over the straight course area. During the run, the tow appeared to slow considerably over the test course. This observation is not borne out by the plot of the tow's performance parameters given in Figure 6.j. Figure 6.j shows that tow speed is relatively constant over the entire course, even during the 4 to 5 minute periods when 10° of rudder were applied.

Figure 6.k shows the last steering test performed on the EXXON LAKE CHARLES which was the downstream Z maneuver part of Run 6. Because there were anchored vessels along the southern part of the course, the Zig-Zag turns were stopped after the second rudder deflection as shown in Figure 6.l. The ranges fixing tow position obtained in the middle part of the course were marginal and contribute to the wobble in the tow's track as plotted in Figure 6.k. Figure 6.l shows that tow speed actually increased during the steering maneuvers indicating that the tow had not reached a steady speed prior to the start of the run.

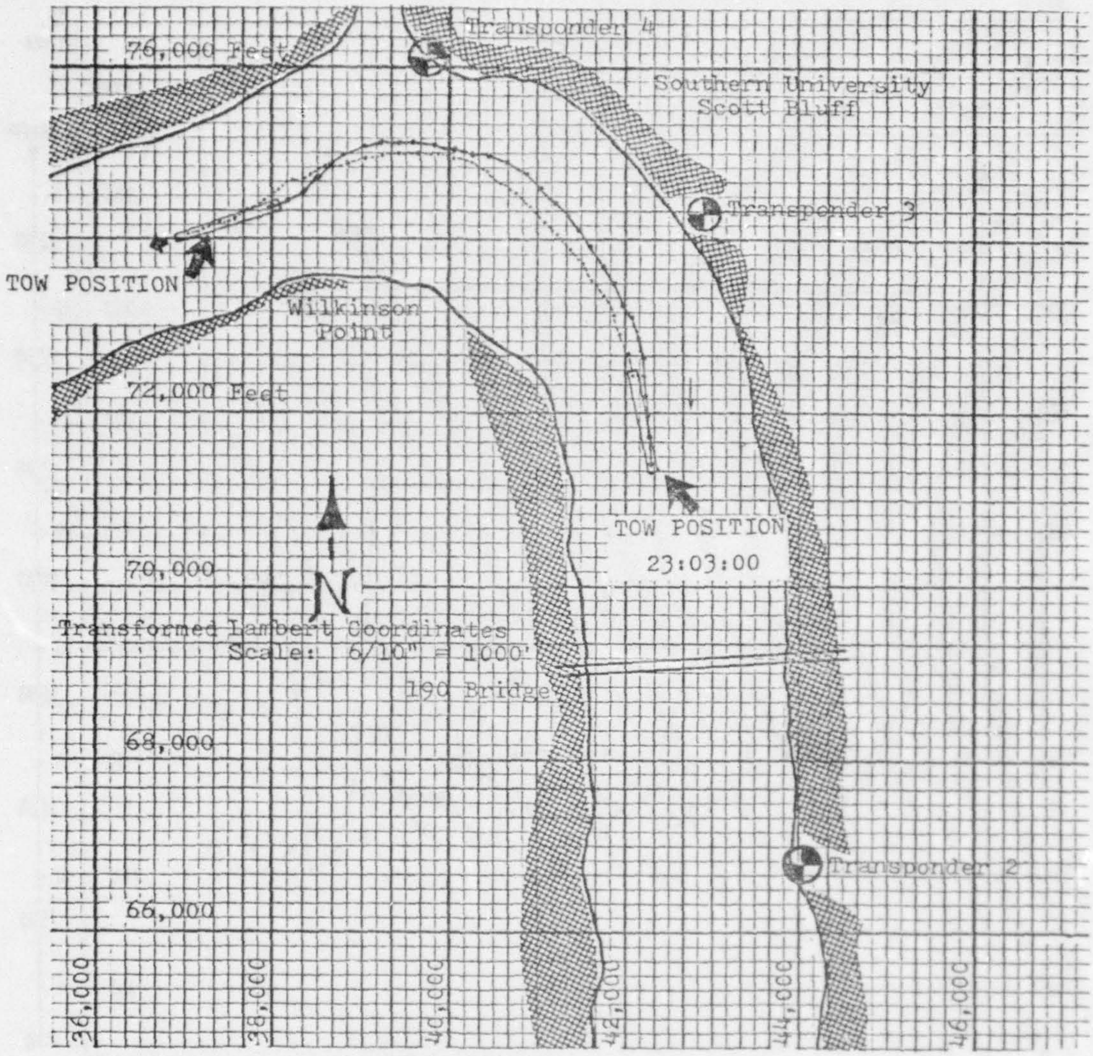
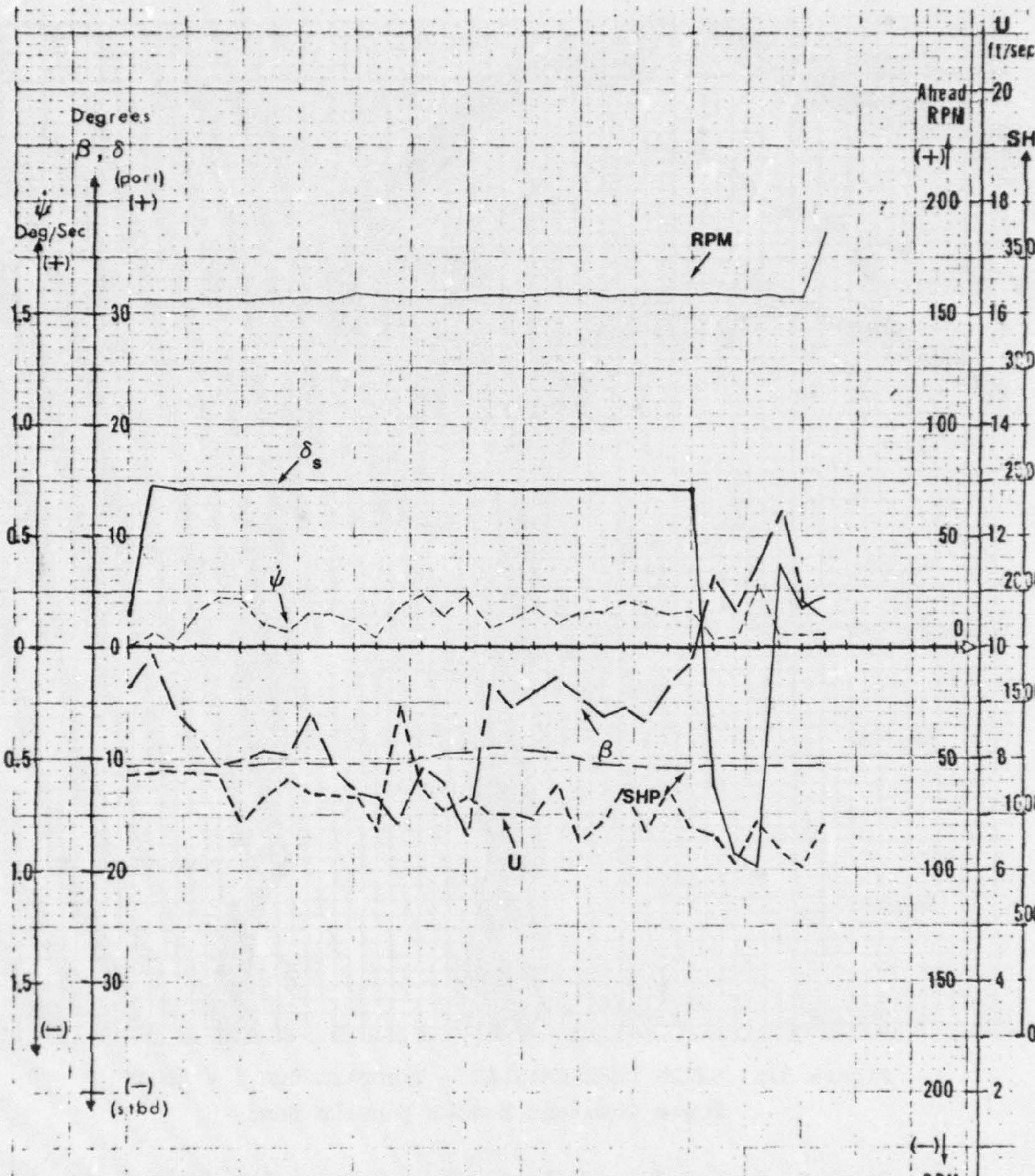


Figure 6.a EXXON LAKE CHARLES - Upstream Run 1 - Half Power Constant Rudder Turn in Bend

Notes to Figure 6.a: Points are plotted at 30 second intervals beginning at 23:03:00 and ending at 23:18:30



Points plotted at 30 second intervals beginning 23: 03 :00

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
$\dot{\psi}$ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 6.b EXXON LAKE CHARLES - Upstream Run 1 - Half Power Steady Turn in Bend

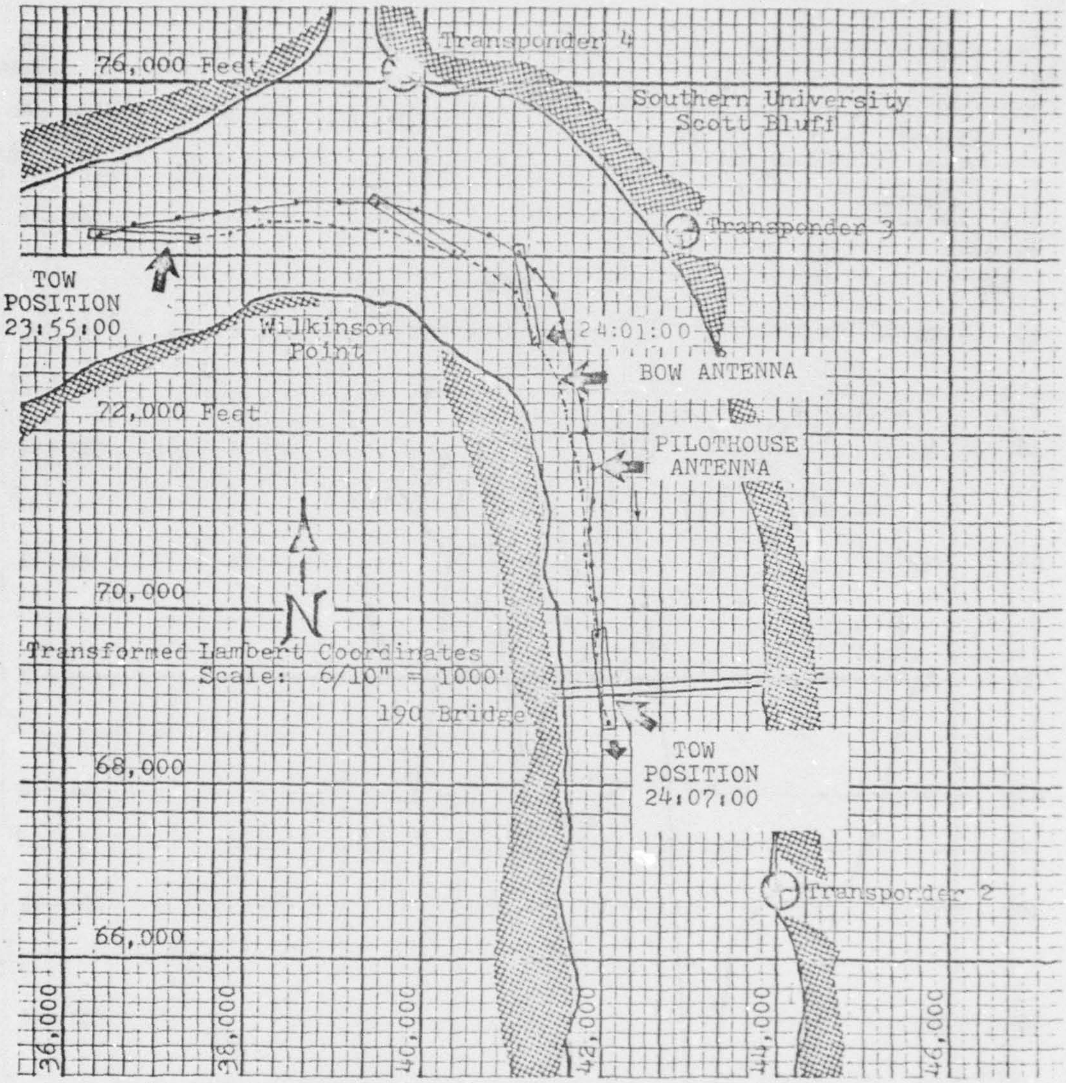


Figure 6.c EXXON LAKE CHARLES - Downstream Run 2 - Half Power Turn in Bend

Notes to Figure 6.c: Positions plotted at 30 second intervals beginning at 23:55:00. At 24:01:00 the bow of the tow influenced by eddy current of bend. (See Section 3.3).

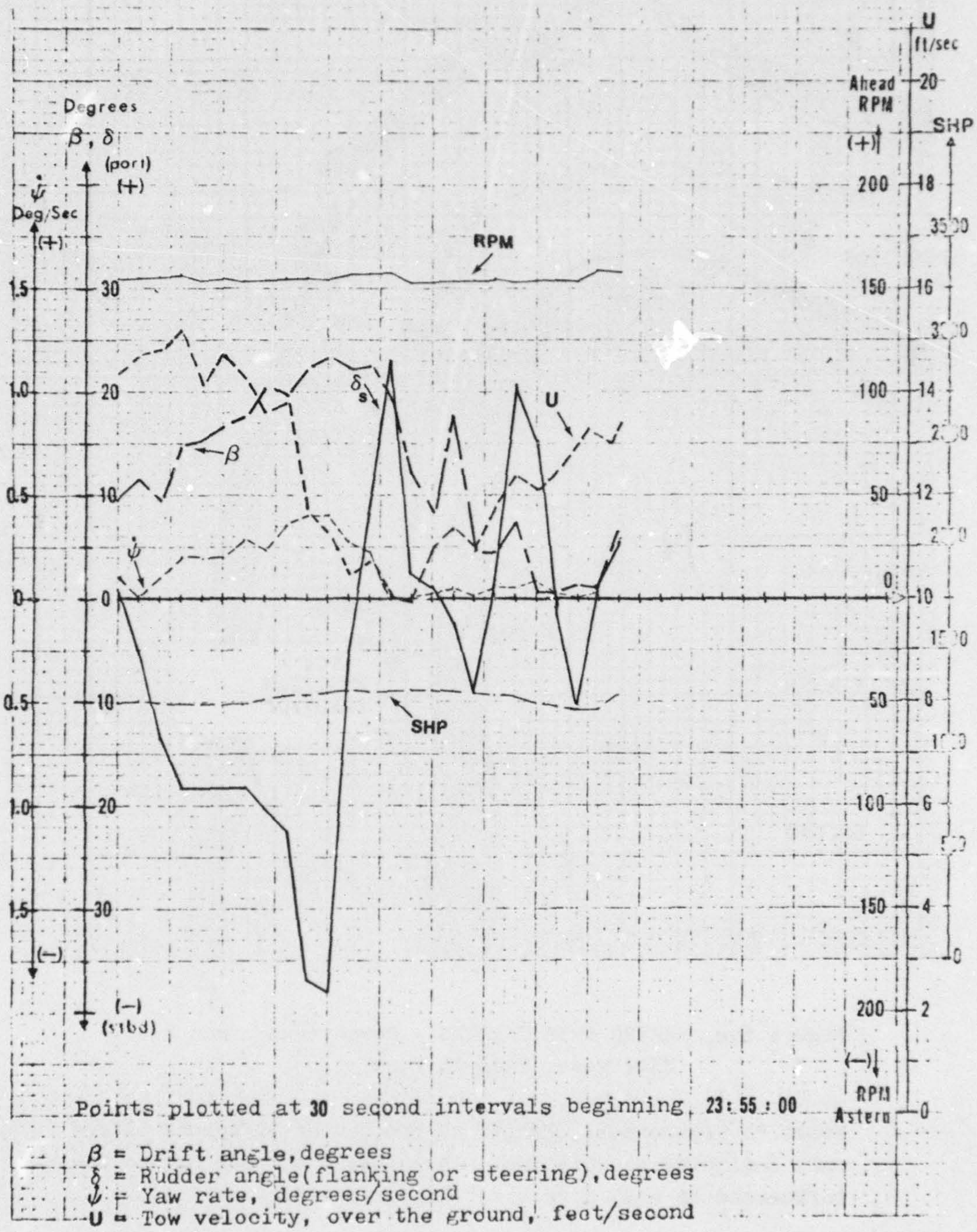


Figure 6.d EXXON LAKE CHARLES - Downstream Run 2 - Half Power Turn in Bend

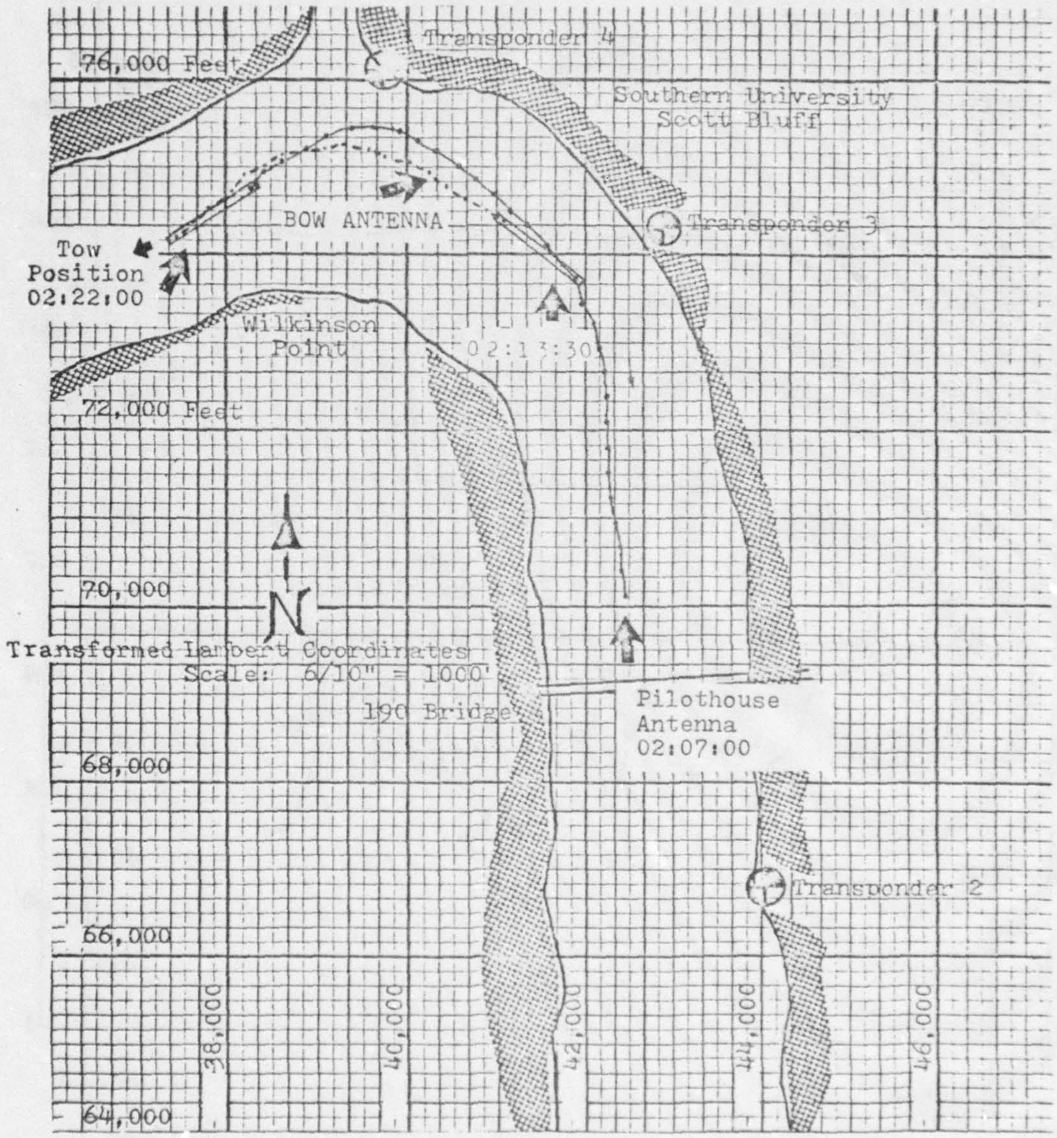


Figure 6.e EXXON LAKE CHARLES - Upstream Run 3 - 3/4 Power Steady Rudder Turn in Bend

Notes to Figure 6.e: Pilothouse and bow antenna positions plotted at 30 second intervals.

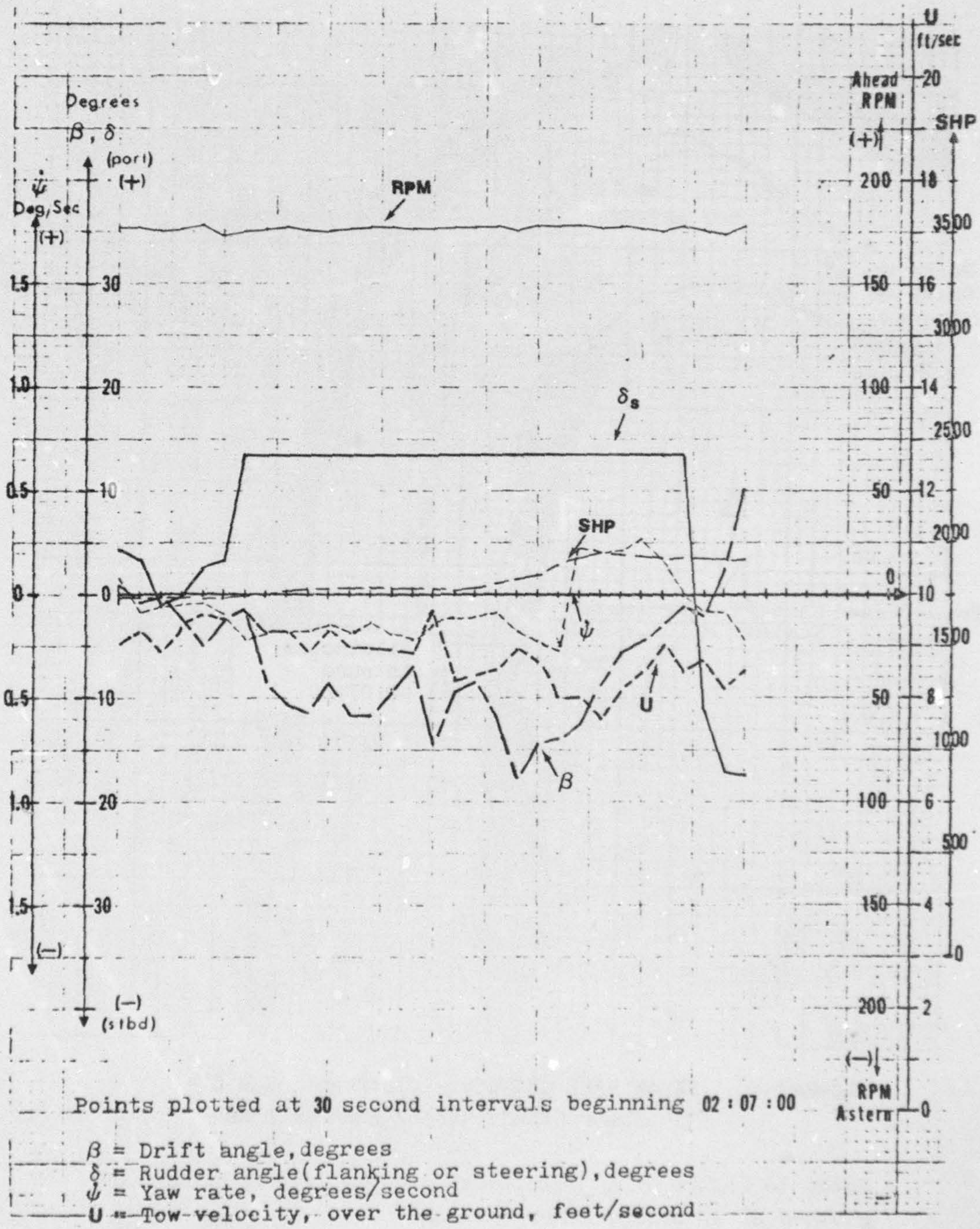


Figure 6.f EXXON LAKE CHARLES - Upstream Run 3 - 3/4 Power Steady Turn in Bend

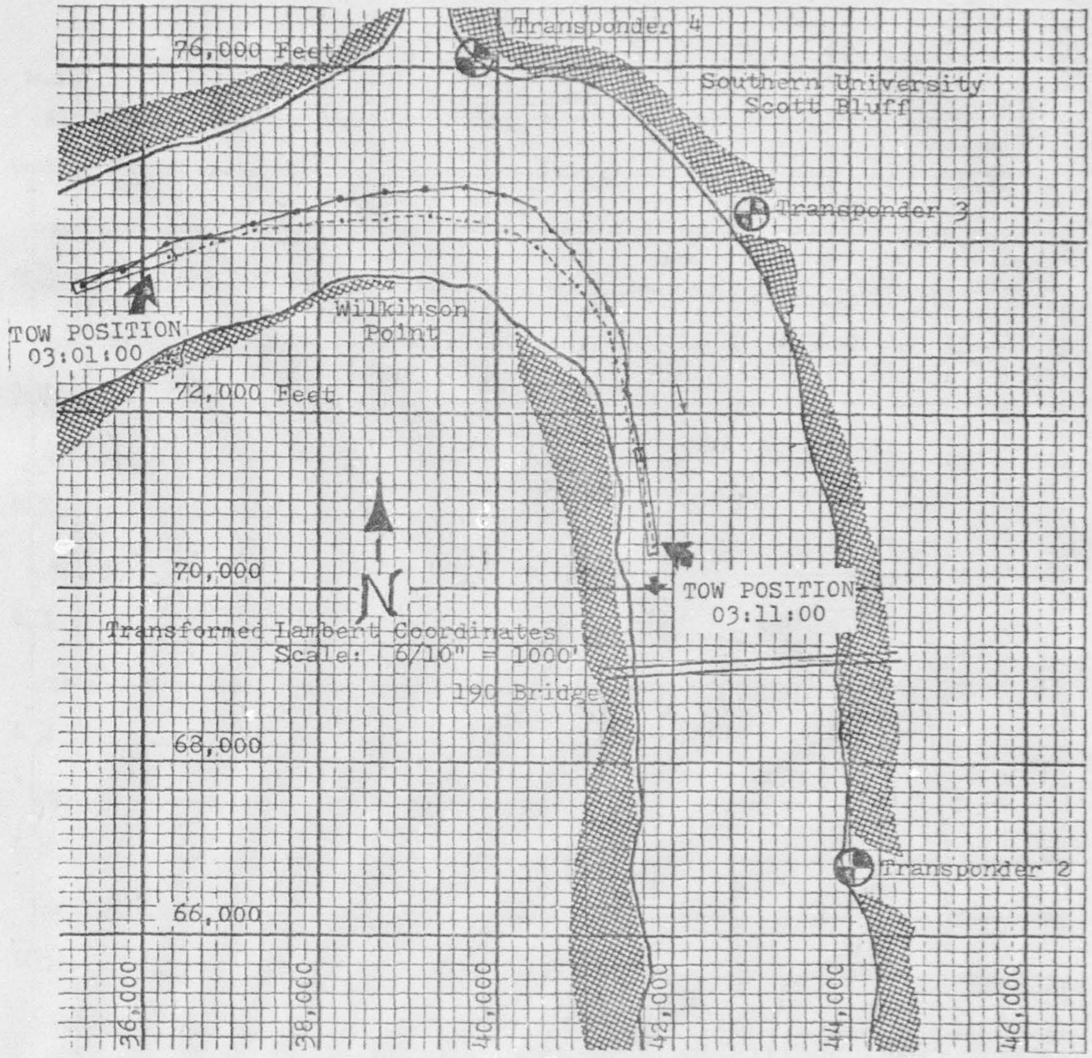


Figure 6.g EXXON LAKE CHARLES - Downstream Run 4 -
3/4 Power Turn Around Bend

Notes to Figure 6.g: Points are plotted at 30 second intervals beginning at 03:01:00 and ending at 03:11:00.

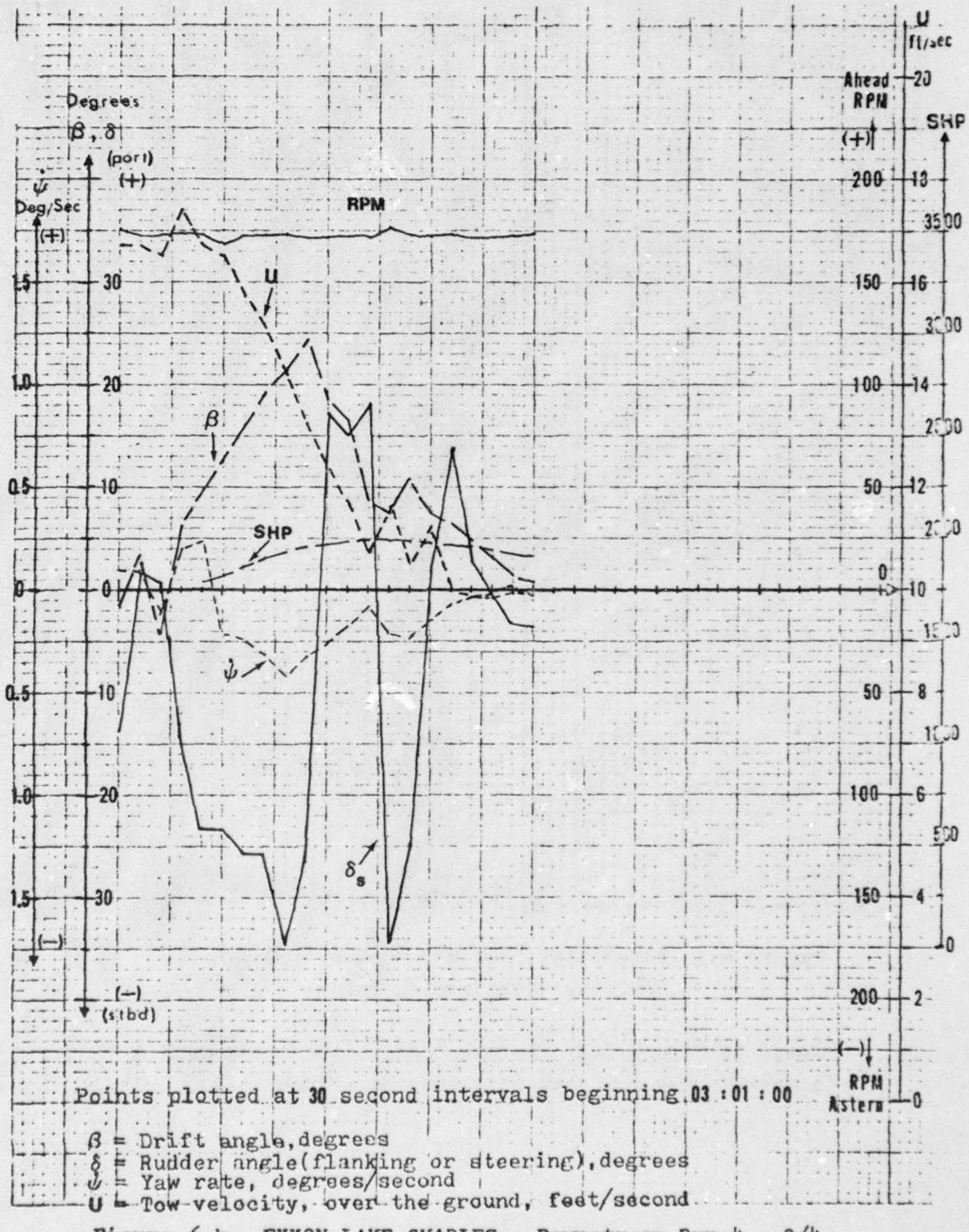


Figure 6.h EXXON LAKE CHARLES - Downstream Run 4 - 3/4

Power Turn Around Bend

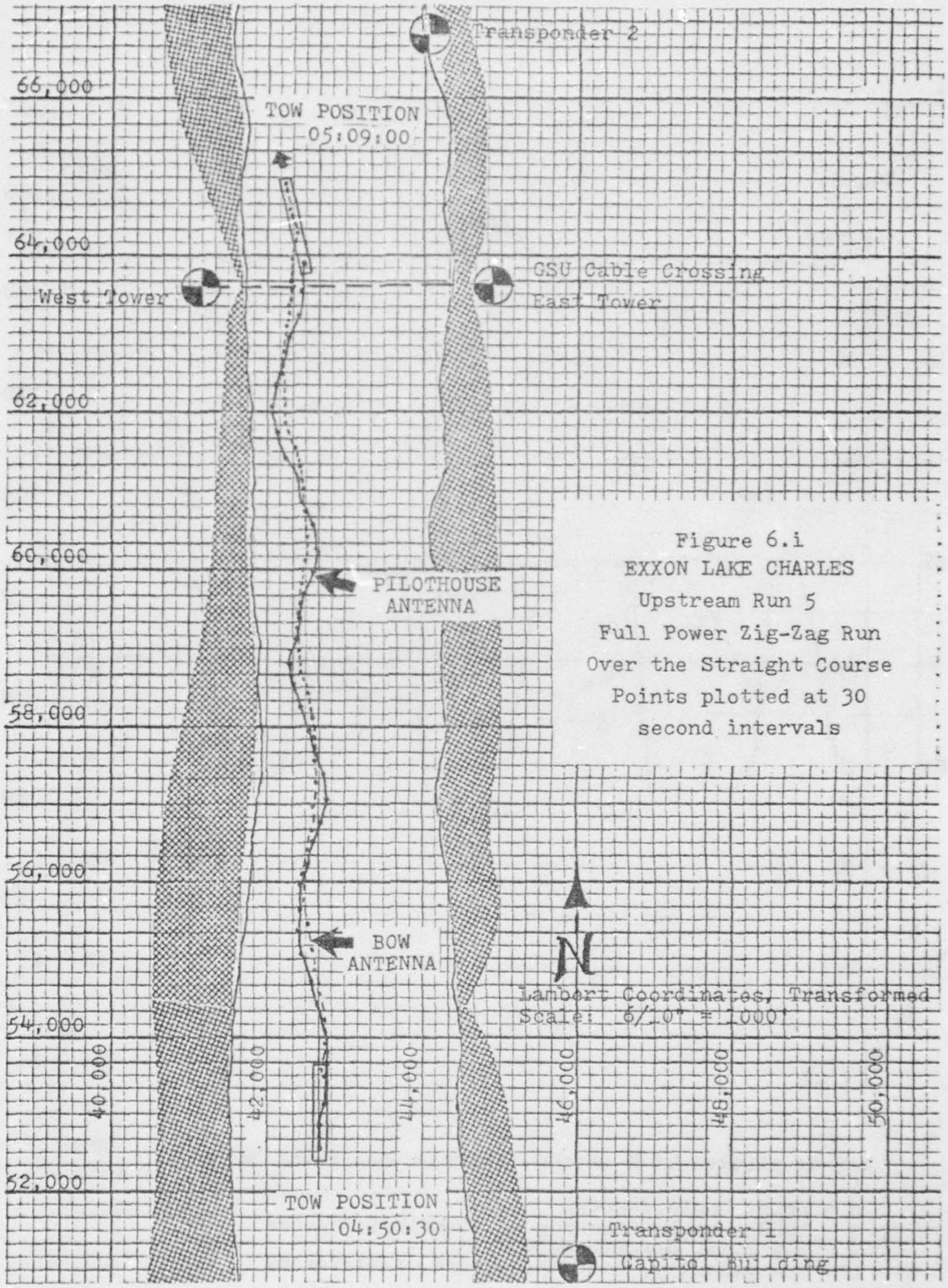
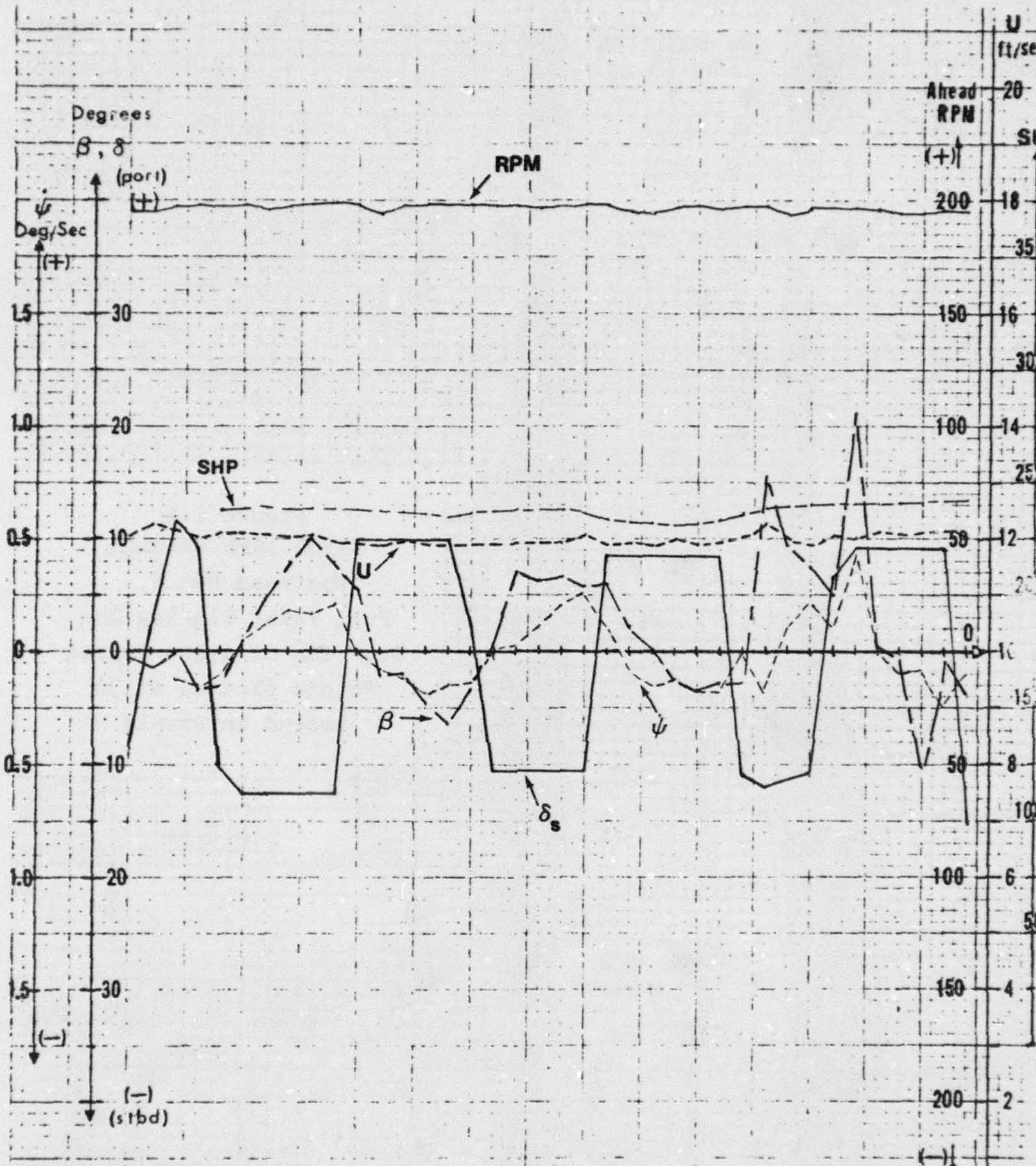


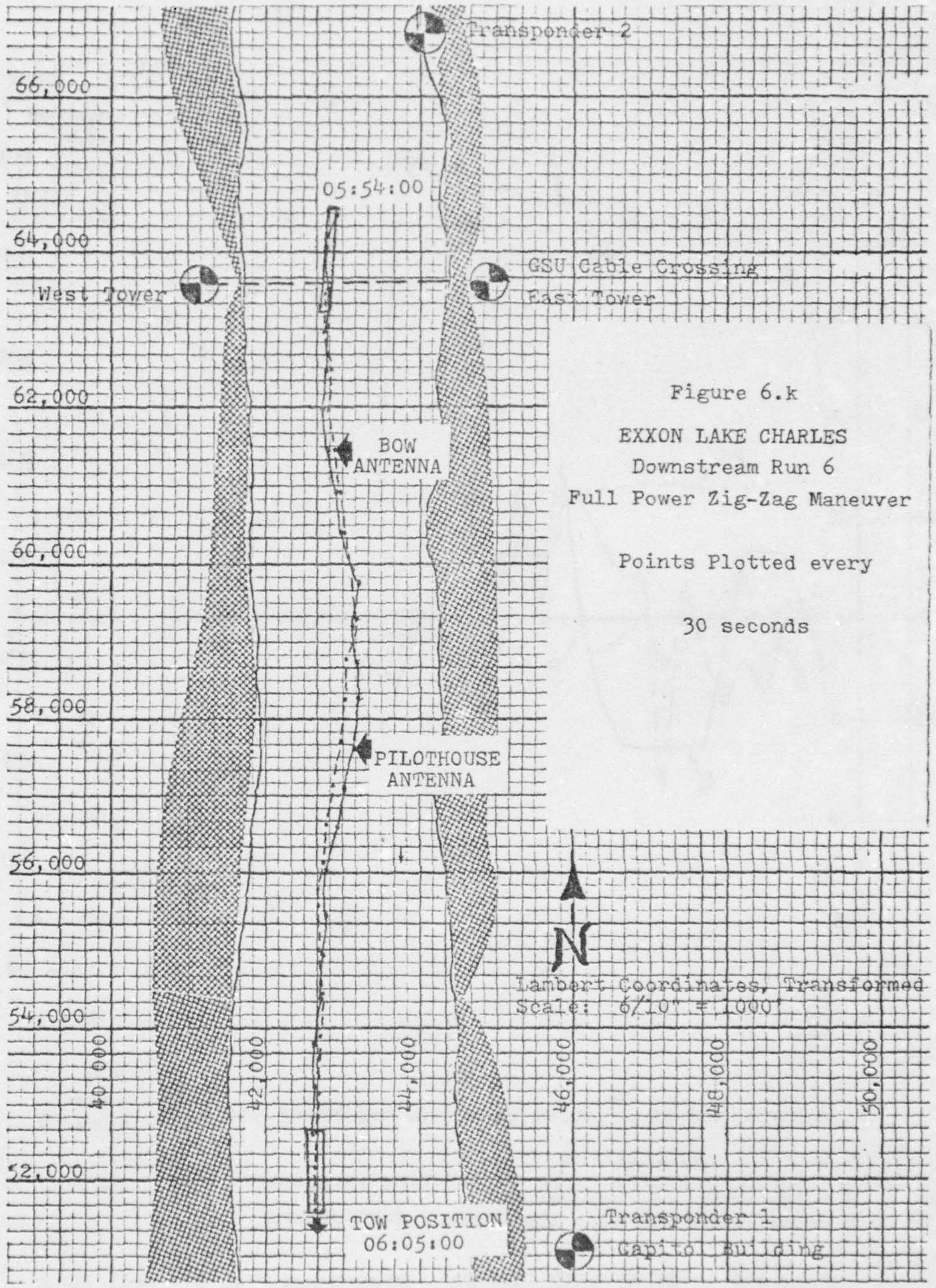
Figure 6.i
EXXON LAKE CHARLES
Upstream Run 5
Full Power Zig-Zag Run
Over the Straight Course
Points plotted at 30
second intervals

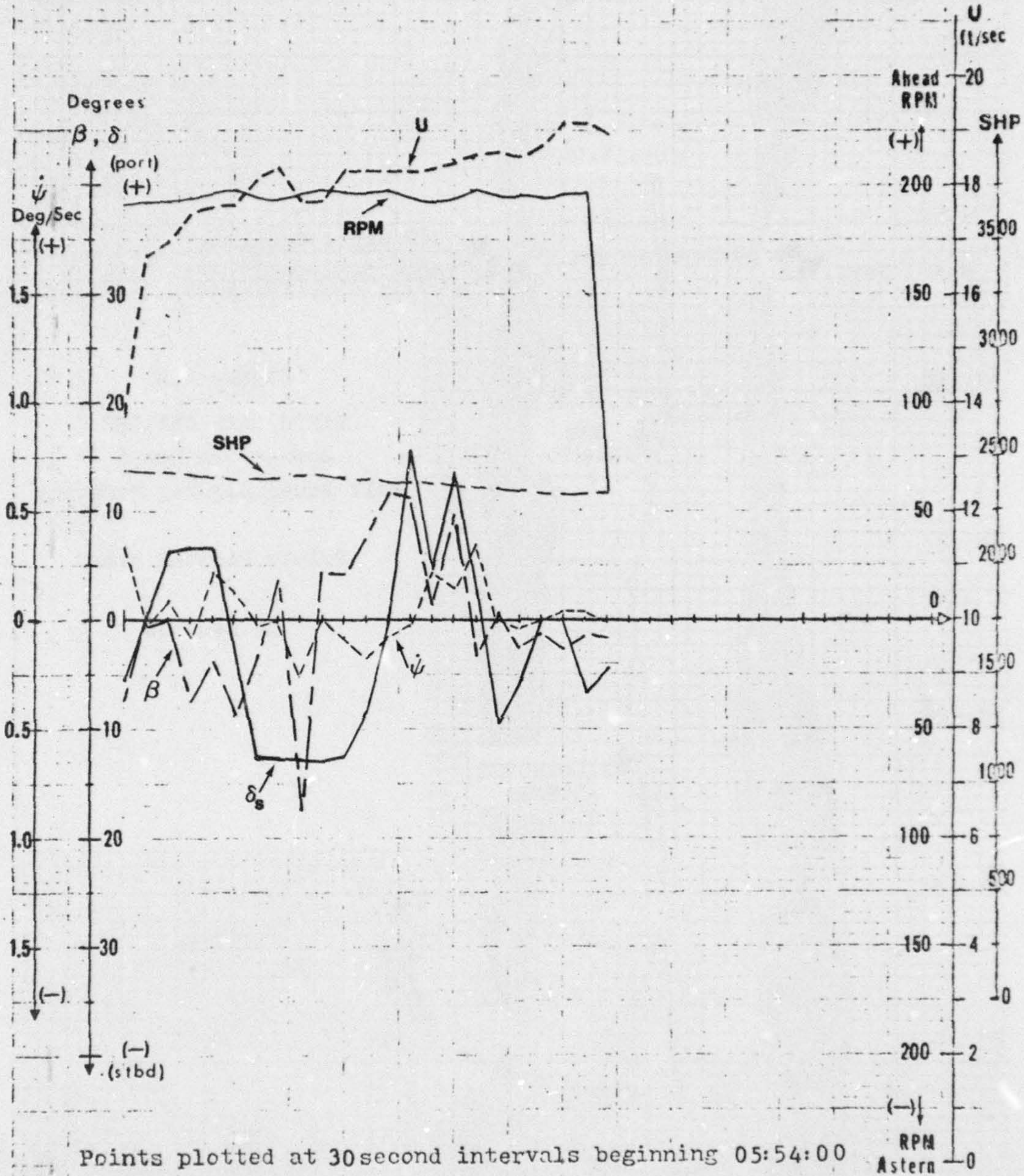


Points plotted at 30 second intervals beginning 04:50:30

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
ψ̇ = Yaw rate, degrees/second
U = Tow velocity, over the ground, foot/second

Figure 6.j EXXON LAKE CHARLES - Upstream Run 5 - Full Power Zig-Zag Run Over Straight Course


Transponder 2
66,000
05:54:00
64,000
GSU Cable Crossing
West Tower
East Tower
62,000
Figure 6.k
EXXON LAKE CHARLES
Downstream Run 6
Full Power Zig-Zag Maneuver
Points Plotted every
30 seconds
BOW ANTENNA
60,000
58,000
PILOTHOUSE ANTENNA
56,000
N
Lambert Coordinates, Transformed
Scale: 6/10" = 1000'
54,000
40,000
42,000
44,000
46,000
48,000
50,000
52,000
TOW POSITION
06:05:00
Transponder 1
Capitol Building



Points plotted at 30 second intervals beginning 05:54:00

β = Drift angle, degrees
δ = Rudder angle (flanking or steering), degrees
$\dot{\psi}$ = Yaw rate, degrees/second
U = Tow velocity, over the ground, feet/second

Figure 6.1 EXXON LAKE CHARLES - Downstream Run 6 - Full Power Zig-Zag over Straight Course

VII. STEERING TEST PERFORMANCE

This section takes a somewhat deeper look into the steering test data portrayed in Sections V and VI. In particular two points are examined: (1) Speed loss due to rudder usage; and (2) Open-wheel versus Kort nozzle performance during turns. Summary performance statistics for the Zig-Zag Runs made by the EXXON NASHVILLE and EXXON LAKE CHARLES are given in the back of this section as Tables 7.A through 7.G. (See the explanation in the beginning of Section VIII regarding the values in these tables). Only one table, Table 7.G, is given for the EXXON LAKE CHARLES downstream Zig-Zag Run 6 because the middle range mark was obscured by a moored vessel and it was impossible to determine when the pilothouse passed abeam the mark.

7.1 Speed Loss Due to Rudder Usage

The use of the rudder is known to reduce tow speed as part of the hydrodynamic forces interacting on the hull and appendages. The extent of this loss, and whether it is desirable or necessary, is another matter. The figures in Sections V and VI show the rather consistant speed loss that occurs during turns. Examination of Table 7.A shows that the upstream Zig-Zag test on the EXXON NASHVILLE using about the ± 10 degrees of rudder decreased the tow's speed 9 percent from 11.8 mph at the start to 10.7 mph through the water at the end of the course. This pattern is shown in Figure 5.j, Section V, in which speed decreases through the fourth rudder deflection. Table 7.B shows the speed increasing as the tow stopped the Z maneuvers approaching the final range. Tables 7.A and 7.B show that minimum and maximum drift angles assumed by the tow are within a few degrees of the minimum and maximum rudder angles applied.

Tables 7.C and 7.D contain summary statistics for the EXXON NASHVILLE's downstream Zig-Zag Run 6. As in the previous case, tow speed decreased over the first leg of the course and increased over the

second. This maneuver is shown plotted in Figure 5.p, Section V, in which the drift angle and rudder angle appear to be amost complementary values. Table 7.C shows the speed loss to be 2 mph through the water, or 16 percent of initial speed over the first leg. The drift angles are 1½ to 2 times the magnitude of the rudder angles used. Table 7.D shows tow increasing slightly as the maneuvers ended.

Tables 7.E and 7.F show the EXXON LAKE CHARLES performing the upstream Zig-Zag run (which was aborted). These runs are shown plotted in Section VI, Figures 6.j and 6.l, respectively. The upstream Z maneuvers showed a speed loss of 1 mph through the water (9 percent) over the first leg with speed increasing during the second leg of the course. Minimum and maximum drift angles and rudder angles were within a few degrees of each other over the first leg. The downstream Z maneuver was inconclusive since the tow had not reached steady speed at the start and was accelerating to full speed over the course when the maneuver was cancelled due to traffic.

Figure 7.a contains plots of the 3 Exxon towboats which have been tested to date. The figure shows the speed loss obtained when making steady upstream turns at constant power using about 15 degrees of rudder. The scatter of points in the figure shows the fluctuation typical of data recorded in the waterway environment. The curve for the EXXON NASHVILLE shows that speed decreased to 85 percent of initial speed after 5 minutes and the EXXON LAKE CHARLES curve indicated a speed loss of about 7 percent after 5 minutes. Because of the wide scatter in data points, the EXXON MEMPHIS speed loss was estimated at 85 percent of initial speed. SHP, RPM, β, $\dot{\psi}$, and δ values corresponding to Figure 7.a were given in Figures 5.b and 6.F for the EXXON NASHVILLE and EXXON LAKE CHARLES, respectively. Reference 1 contains a discussion of the EXXON MEMPHIS parameter variations during this turn. The downstream turns show the pilots using larger rudder angles than those used during the upstream turns. With increased

rudder, drift angles are larger and speed loss is greater.

7.2 Open-Wheel Versus Kort Nozzle Turning Performance

Figure 7.b shows the averaged speed loss, drift angle (β), and yaw rate ($\dot{\psi}$) obtained by averaging these values for 60 second periods during 6 minutes of a constant rudder, constant power turn for the 3 Exxon tows tested. In this way the volatility of the data was removed while maintaining essential comparability between the tows.

The speed loss comparison was based on the speed of each tow as it progressed through the turn as a fraction of its average speed during the 30 seconds prior to the rudder deflection. This method tends to neutralize current, weather, and depth variation between test periods. The initial average speed over the ground of the EXXON MEMPHIS was 10.49 fps and rudder was 14.7°, EXXON NASHVILLE speed was 9.31 fps and rudder 16°, and the EXXON LAKE CHARLES speed was 7.96 fps and rudder 14.1°. Each average value for a given minute of the turn was plotted at the middle point of that minute.

Figure 7.b shows that the EXXON NASHVILLE had the greatest initial speed loss and the EXXON LAKE CHARLES the least overall. The EXXON MEMPHIS had virtually no speed loss the first minute but showed the greatest speed loss through the first 6 minutes of turn.

The drift angles obtained by the tow's show that the largest drift angle was obtained by the slowest speed tow - - the EXXON LAKE CHARLES. Also, the smallest drift angle was obtained by the EXXON NASHVILLE which used the largest rudder angle for the turn. The EXXON MEMPHIS and NASHVILLE both achieved reasonably constant turning rates with the EXXON MEMPHIS yaw rate marginally greater. As these curves show, the performance of the two sister towboats were so close, that recognizing the differences in tow displacement and waterway test

conditions, it would be difficult to identify which was the more efficient.

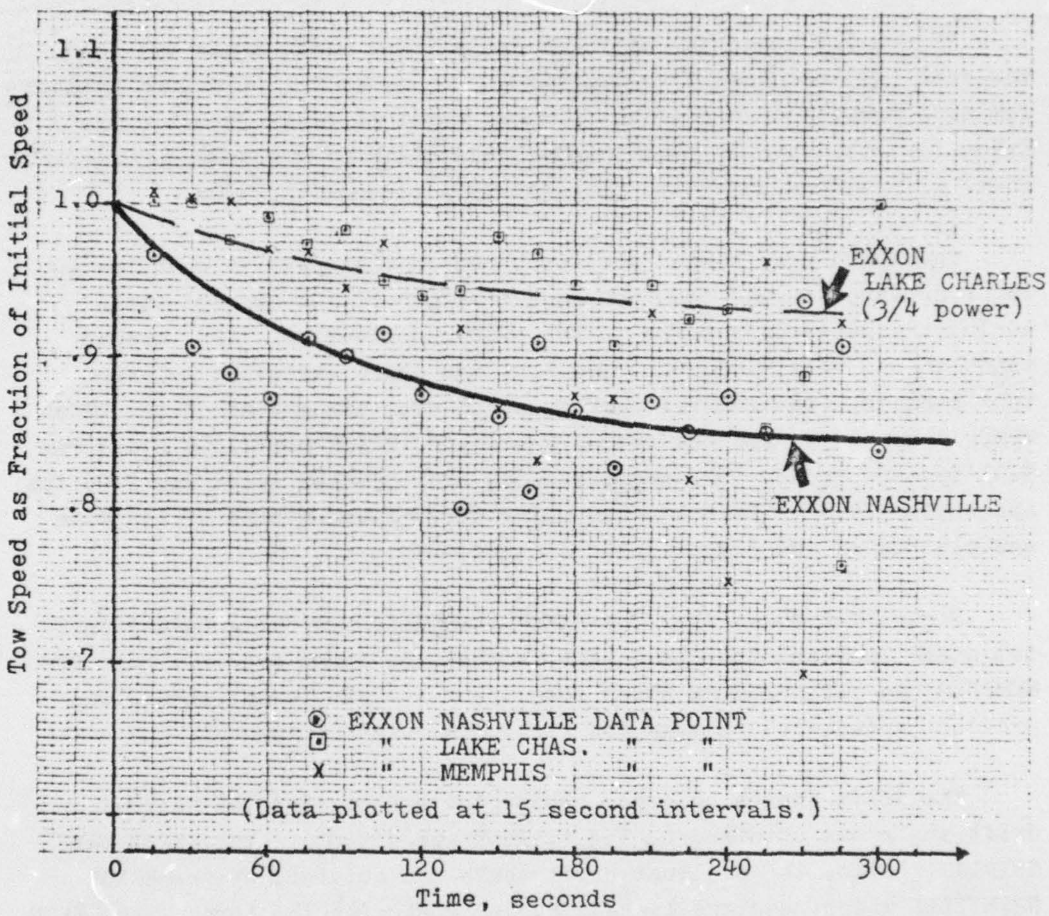


Figure 7.a Upstream Constant Rudder Turn

Notes to Figure 7.a: Time is measured from when the rudder is deflected at the start of the turn. EXXON MEMPHIS data taken from Reference 1 workpapers. The EXXON NASHVILLE and EXXON MEMPHIS are at half power. Each tow is using about 15 degrees of left rudder.

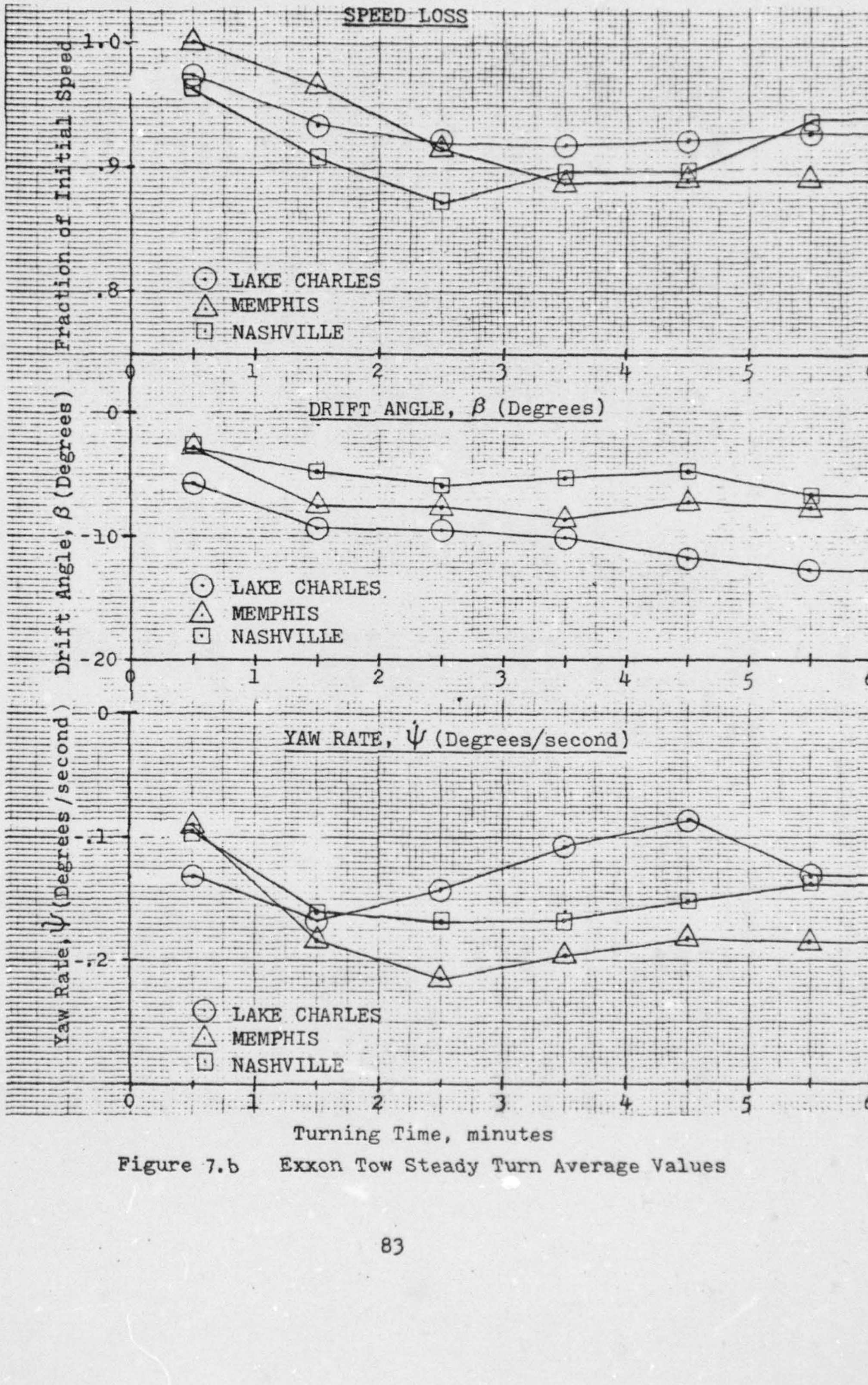


Figure 7.b Exxon Tow Steady Turn Average Values

Table 7.A

EXXON NASHVILLE - Upstream Run 5

Full Power Zig-Zag Run Over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=10.1649 END =10.250[illegible] TOTAL SECONDS= 495

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52843.3	43051.8	58536.4	42913.0	5694.7	5849.7
BOW ANTENNA	53857.7	43068.6	59548.3	42776.2	5698.2	5753.3
CENT. GRAV.	53359.8	43060.9	59048.5	42843.8	5692.9	5760.4

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	12.8433	11.0220	11.6614	10.7452(10.2132)	13.1056(10.1659)
(MPH)	8.7568	7.5150	7.9510	7.3262(10.2132)	8.9357(10.1659)
VELOCITY T.W.(FPS)	17.2632	15.7629	16.2015	15.2803(10.2132)	17.5164(10.1659)
(MPH)	11.7704	10.7474	11.0465	10.4183(10.2132)	11.9430(10.1659)
PORT ENGINE SHP	1690.1	1728.9	1730.1	1690.1(10.1649)	1749.2(10.2254)
SHAFT RPM	223.1	221.0	224.9	220.7(10.2501)	229.7(10.2320)
STBD ENGINE SHP	1641.7	1630.9	1640.2	1630.9(10.2503)	1646.7(10.1846)
SHAFT RPM	210.4	208.8	210.5	204.4(10.1740)	214.6(10.2016)
BOTH ENGINE SHP	3331.8	3359.8	3370.3	3331.8(10.1649)	3385.3(10.2238)
AVE. SHAFT RPM	216.7	214.9	217.7	213.3(10.2203)	221.0(10.2304)
STEER RUDDR(DEG,PORT+)	4.2	-8.5	1.4	-8.5(10.2456)	13.0(10.1657)
FLANK RUDDR(DEG,PORT+)	.6	.9	.5	.2(10.2319)	1.0(10.2130)
DRIFT(DEG.RES+ON PORT)	.1991	5.8007	.4126	-10.4847(10.2302)	11.3382(10.2056)
YAW RATE(DEG/SECOND)	-.0277	.1064	-.0173	-.2904(10.2333)	.2694(10.2017)
YAW ACCEL(DEG/SEC/SEC)	-.0006	.0108	.0002	-.0345(10.2329)	.0328(10.2359)
XY ACCEL(FT/SEC/SEC)	.0600	.1564	.1034	.0020(10.1850)	.3308(10.2220)
DEPTH AT BOW(FEET)	50.1	52.7	51.9	49.4(10.1852)	55.6(10.2335)
DEPTH AT STERN(FEET)	46.7	55.0	51.6	46.3(10.1752)	56.0(10.2320)
DIST. OFF W.BANK(FEET)	1317.8	981.8	1071.4	981.8(10.2503)	1317.8(10.1649)
E.BANK(FEET)	1440.3	1271.6	1435.6	1253.2(10.2430)	1580.6(10.1915)

Table 7.B

EXXON NASHVILLE - Upstream Run 5

Full Power Zig-Zag Run Over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS)   START=10.2503   END =10.3230   TOTAL SECONDS= 448

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58536.4	42913.0	63622.8	42955.3	5086.7	5205.0
BOW ANTENNA	59548.3	42776.2	64643.6	42934.6	5097.7	5131.8
CENT. GRAV.	59048.5	42843.8	64140.0	42945.3	5092.5	5139.1

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	11.0220	12.7726	11.4978	10.2397(10.2632)	12.8636(10.3144)
(MPH)	7.5150	8.7086	7.8394	6.9816(10.2632)	8.7707(10.3144)
VELOCITY T.W.(FPS)	15.7629	17.1547	16.0945	15.0628(10.2632)	17.2393(10.3144)
(MPH)	10.7474	11.6964	10.9735	10.2701(10.2632)	11.7541(10.3144)
PORT ENGINE SHP	1728.9	1717.5	1727.1	1715.7(10.2621)	1739.6(10.2852)
SHAFT RPM	221.0	224.5	223.7	220.6(10.2758)	227.8(10.2854)
STBD ENGINE SHP	1630.9	1637.8	1628.9	1622.6(10.2731)	1637.8(10.3230)
SHAFT RPM	208.8	209.7	209.2	202.6(10.2747)	213.2(10.2606)
BOTH ENGINE SHP	3359.8	3355.3	3356.0	3342.2(10.2622)	3366.1(10.2852)
AVE. SHAFT RPM	214.9	217.1	216.5	212.2(10.2759)	219.1(10.2550)
STEER RUDDR(DEG,PORT+)	-8.5	1.3	1.3	-9.5(10.3055)	12.7(10.2653)
FLANK RUDDR(DEG,PORT+)	.9	.6	.7	.4(10.2901)	1.1(10.2623)
DRIFT(DEG,RES+ON PORT)	5.8007	1.4827	.7965	-14.2212(10.2833)	15.4833(10.3130)
YAW RATE(DEG/SECOND)	.1064	.0395	.0147	-.3035(10.2811)	.2585(10.2647)
YAW ACCEL(DEG/SEC/SEC)	.0108	-.0013	-.0001	-.0602(10.3136)	.0552(10.2827)
XY ACCEL(FT/SEC/SEC)	.1564	.0249	.1250	.0052(10.3156)	.5216(10.3136)
DEPTH AT BOW(FEET)	52.7	46.3	44.6	41.3(10.3017)	52.7(10.2503)
DEPTH AT STERN(FEET)	55.0	49.5	46.6	40.0(10.3009)	55.0(10.2503)
DIST. OFF W.BANK(FEET)	981.8	1165.8	1063.2	919.3(10.2645)	1184.3(10.3130)
E.BANK(FEET)	1271.6	1408.7	1337.6	1271.6(10.2503)	1408.7(10.3230)

Table 7.C

EXXON NASHVILLE - Downstream Run 6

Full Power Zig-Zag Run over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=12.0041 END =12.0509 TOTAL SECONDS= 269

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	63609.3	42287.4	58398.0	42911.9	5248.6	5369.8
BOW ANTENNA	62596.7	42231.6	57353.1	42750.8	5269.2	5313.0
CENT. GRAV.	63092.8	42258.7	57886.9	42832.2	5237.4	5276.2

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	22.0508	19.5861	19.6911	15.8283(12.0207)	23.9775(12.0331)
(MPH)	15.0346	13.3542	13.4258	10.7920(12.0207)	16.3483(12.0331)
VELOCITY T.W.(FPS)	18.1079	15.1356	15.4361	11.8730(12.0207)	19.8165(12.0331)
(MPH)	12.3463	10.3198	10.5246	8.0953(12.0207)	13.5113(12.0331)
PORT ENGINE SHP	1728.7	1725.9	1728.7	1723.2(12.0432)	1732.4(12.0218)
SHAFT RPM	212.0	211.1	212.7	209.5(12.0310)	216.6(12.0204)
STBD ENGINE SHP	1638.5	1622.6	1648.2	1622.6(12.0509)	1658.7(12.0310)
SHAFT RPM	213.0	213.7	213.3	208.4(12.0318)	216.5(12.0347)
BOTH ENGINE SHP	3367.2	3348.5	3376.9	3348.5(12.0509)	3389.0(12.0301)
AVE. SHAFT RPM	212.5	212.4	213.0	209.2(12.0318)	215.5(12.0201)
STEER RUDDR(DEG,PORT+)	4.3	6.9	-1.8	-10.1(12.0230)	11.9(12.0104)
FLANK RUDDR(DEG,PORT+)	-1.4	-.4	-1.1	-1.7(12.0223)	-.4(12.0445)
DRIFT(DEG,RES+ON PORT)	9.6127	10.5863	2.3340	-21.0926(12.0207)	17.8536(12.0335)
YAW RATE(DEG/SECOND)	-.2255	-.1573	-.0216	-.7722(12.0330)	.5756(12.0207)
YAW ACCEL(DEG/SEC/SEC)	.0017	-.0051	.0002	-.0650(12.0423)	.0849(12.0339)
XY ACCEL(FT/SEC/SEC)	.1156	.1793	.3059	.0118(12.0233)	.9569(12.0214)
DEPTH AT BOW(FEET)	33.7	54.9	45.2	33.7(12.0041)	54.9(12.0509)
DEPTH AT STERN(FEET)	36.4	53.9	49.8	36.4(12.0041)	57.0(12.0430)
DIST. OFF W.BANK(FEET)	476.7	893.4	629.2	476.7(12.0041)	893.4(12.0509)
E.BANK(FEET)	2070.0	1459.9	1696.7	1458.3(12.0454)	2070.0(12.0041)

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Table 7.D

EXXON NASHVILLE - Downstream Run 6

Full Power Zig-Zag Run over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=12.0509 END =12.0952 TOTAL SECONDS= 284

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58398.0	42911.9	52858.9	42975.7	5539.5	5606.5
BOW ANTENNA	57353.1	42750.8	51829.8	43245.5	5545.4	5572.5
CENT. GRAV.	57886.9	42832.2	52358.6	43106.3	5535.2	5574.9

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	19.5861	19.5975	19.6987	19.1009(12.0907)	20.4911(12.0712)
(MPH)	13.3542	13.3619	13.4310	13.0233(12.0907)	13.9712(12.0712)
VELOCITY T.W.(FPS)	15.1356	15.3491	15.3318	14.8066(12.0742)	16.0939(12.0712)
(MPH)	10.3198	10.4653	10.4535	10.0954(12.0742)	10.9731(12.0712)
PORT ENGINE SHP	1725.9	.0	922.1	.0(12.0740)	1742.7(12.0739)
SHAFT RPM	211.1	212.0	212.3	207.6(12.0634)	218.3(12.0517)
STBD ENGINE SHP	1622.6	.0	853.1	.0(12.0740)	1622.6(12.0509)
SHAFT RPM	213.7	207.3	211.4	206.4(12.0612)	220.0(12.0518)
BOTH ENGINE SHP	3348.5	.0	1775.2	.0(12.0740)	3349.5(12.0739)
AVE. SHAFT RPM	212.4	209.7	211.9	207.7(12.0625)	218.7(12.0517)
STEER RUDDR(DEG,PORT+)	6.9	-11.2	5.2	-11.2(12.0951)	11.6(12.0655)
FLANK RUDDR(DEG,PORT+)	-.4	-.3	-1.2	-1.8(12.0844)	-.2(12.0933)
DRIFT(DEG,RES+ON PORT)	10.5863	-2.2967	-3.0855	-9.7401(12.0824)	14.7234(12.0535)
YAW RATE(DEG/SECOND)	-.1573	-.1411	.0820	-.1596(12.0510)	.2393(12.0527)
YAW ACCEL(DEG/SEC/SEC)	-.0051	-.0053	.0000	-.0447(12.0534)	.0455(12.0521)
XY ACCEL(FT/SEC/SEC)	.1793	.0518	.0850	.0021(12.0730)	.5544(12.0528)
DEPTH AT BOW(FEET)	54.9	48.3	51.8	48.3(12.0952)	55.0(12.0522)
DEPTH AT STERN(FEET)	53.9	35.1	47.7	35.1(12.0952)	53.9(12.0509)
DIST. OFF W.BANK(FEET)	893.4	1543.9	1122.9	893.4(12.0509)	1543.9(12.0952)
E.BANK(FEET)	1459.9	1414.3	1538.7	1414.3(12.0952)	1610.4(12.0712)

Table 7.E

EXXON LAKE CHARLES - Upstream Run 5

Full Power Zig-Zag Run over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= 4.5102 END = 5.0018 TOTAL SECONDS= 557

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52857.0	42672.5	58399.1	42365.5	5550.5	5705.9
BOW ANTENNA	53892.4	42715.2	59442.3	42410.7	5558.3	5604.1
CENT. GRAV.	53364.8	42693.5	58906.9	42387.6	5550.4	5608.3

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	11.2934-	9.8101	10.0876	9.2711(4.5839)	11.3436(4.5106)
(MPH)	7.7000	6.6887	6.8779	6.3212(4.5839)	7.7342(4.5106)
VELOCITY T.W.(FPS)	15.9107	14.3843	14.6733	13.8410(4.5839)	15.9608(4.5106)
(MPH)	10.8482	9.8075	10.0045	9.4370(4.5839)	10.8823(4.5106)
PORT ENGINE SHP	1218.1	1243.7	1226.1	1205.6(4.5732)	1246.8(5.0005)
SHAFT RPM	199.5	199.3	199.9	197.6(4.5254)	201.7(4.5150)
STBD ENGINE SHP	1154.3	1121.8	1146.4	1121.8(5.0018)	1157.0(4.5218)
SHAFT RPM	193.1	195.2	194.3	189.8(4.5928)	198.9(4.5503)
BOTH ENGINE SHP	.0	2365.5	2087.1	.0(4.5102)	2388.7(4.5444)
AVE. SHAFT RPM	196.3	197.3	197.1	194.9(4.5601)	199.6(4.5502)
STEER RUDDR(DEG,PORT+)	3.0	-10.4	-1.5	-11.6(4.5419)	11.9(4.5113)
FLANK RUDDR(DEG,PORT+)	.3	.5	.3	-.0(4.5242)	.6(4.5934)
DRIFT(DEG,RES+ON PORT)	-1.3141	11.9876	1.6364	-7.4726(4.5707)	12.3033(5.0016)
YAW RATE(DEG/SECOND)	.0270	.1335	.0003	-.2158(4.5711)	.2573(4.5411)
YAW ACCEL(DEG/SEC/SEC)	-.0041	.0040	.0001	-.0144(4.5418)	.0168(4.5822)
XY ACCEL(FT/SEC/SEC)	.0223	.0818	.0496	.0024(4.5317)	.1192(4.5737)
DEPTH AT BOW(FEET)	39.0	59.2	53.6	39.0(4.5102)	60.3(4.5903)
DEPTH AT STERN(FEET)	49.5	53.5	54.3	49.0(4.5215)	60.0(4.5758)
DIST. OFF W.BANK(FEET)	963.1	635.3	723.7	621.5(4.5953)	963.1(4.5102)
E.BANK(FEET)	1777.8	1756.0	1949.7	1756.0(5.0018)	2116.6(4.5720)

Table 7.F

EXXON LAKE CHARLES - Upstream Run 5

Full Power Zig-Zag Run over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= 5.0018 END = 5.0908 TOTAL SECONDS= 531

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58399.1	42365.5	63653.4	42421.6	5254.8	5445.5
BOW ANTENNA	59442.3	42410.7	64694.7	42289.2	5253.9	5374.1
CENT. GRAV.	58906.9	42387.6	64157.1	42357.6	5250.3	5339.7

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	9.8101	10.8666	10.0752	9.3933(5.0104)	12.1636(5.0421)
(MPH)	6.6887	7.4090	6.8694	6.4045(5.0104)	8.2934(5.0421)
VELOCITY T.W.(FPS)	14.3843	15.4491	14.6082	13.9487(5.0112)	16.2139(5.0421)
(MPH)	9.8075	10.5335	9.9601	9.5105(5.0112)	11.0550(5.0421)
PORT ENGINE SHP	1243.7	1300.4	1259.8	1205.6(5.0225)	1300.4(5.0908)
SHAFT RPM	199.3	199.7	200.0	198.3(5.0451)	202.1(5.0825)
STBD ENGINE SHP	1121.8	1131.5	1125.0	1109.0(5.0120)	1132.4(5.0356)
SHAFT RPM	195.2	192.4	192.8	188.9(5.0154)	196.5(5.0433)
BOTH ENGINE SHP	2365.5	2431.8	2384.9	2323.2(5.0209)	2431.8(5.0908)
AVE. SHAFT RPM	197.3	196.1	196.4	194.0(5.0500)	198.1(5.0433)
STEER RUDDR(DEG,PORT+)	-10.4	9.2	1.7	-12.1(5.0405)	9.3(5.0845)
FLANK RUDDR(DEG,PORT+)	.5	-.0	.3	-.1(5.0857)	.9(5.0645)
DRIFT(DEG,RES+ON PORT)	11.9876	-3.6825	.8448	-17.7754(5.0443)	23.4606(5.0424)
YAW RATE(DEG/SECOND)	.1335	-.1188	-.0183	-.3140(5.0645)	.4621(5.0444)
YAW ACCEL(DEG/SEC/SEC)	.0040	-.0068	-.0004	-.0836(5.0639)	.0746(5.0436)
XY ACCEL(FT/SEC/SEC)	.0818	.2228	.1161	.0024(5.0233)	.6234(5.0435)
DEPTH AT BOW(FEET)	59.2	34.1	46.0	34.1(5.0908)	59.2(5.0018)
DEPTH AT STERN(FEET)	53.5	33.4	40.5	33.2(5.0822)	53.5(5.0018)
DIST. OFF W.BANK(FEET)	635.3	482.5	583.8	482.0(5.0851)	667.1(5.0225)
E.BANK(FEET)	1756.0	2097.6	1821.7	1560.5(5.0230)	2099.0(5.0851)

Table 7.G

EXXON LAKE CHARLES - Downstream Run 6

Full Power Partial Zig-Zag Run over Entire Straight Course

SUMMARY TIMES(HH.MMSS) START= 5.5454 END = 6.0447 TOTAL SECONDS= 594

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	63616.0	42823.1	52880.9	42628.7	10736.9	10888.2
BOW ANTENNA	62583.0	42829.4	51851.8	42648.6	10732.7	10832.2
CENT. GRAV.	63107.9	42826.0	52372.7	42638.4	10736.8	10807.5

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	16.7155	19.1847	18.2246	16.6828(5.5455)	19.8542(5.5813)
(MPH)	11.3969	13.0804	12.4259	11.3746(5.5455)	13.5370(5.5813)
VELOCITY T.W.(FPS)	11.5980	14.8566	13.5551	11.5658(5.5455)	14.9990(5.5813)
(MPH)	7.9078	10.1295	9.2421	7.8858(5.5455)	10.2266(5.5813)
PORT ENGINE SHP	1281.5	1210.0*	1249.0	1210.0(6.0345)	1281.5(5.5454)
SHAFT RPM	194.6	170.0*	198.3	170.0(6.0447)	201.3(6.0203)
STBD ENGINE SHP	1142.0	1124.0*	1132.2	1124.0(6.0345)	1143.0(5.5723)
SHAFT RPM	188.9	171.3*	192.1	171.3(6.0447)	196.8(5.5822)
BOTH ENGINE SHP	2423.5	2334.0*	2381.2	2334.0(6.0345)	2423.5(5.5454)
AVE. SHAFT RPM	191.8	170.6*	195.2	170.6(6.0447)	198.3(5.5821)
STEER RUDDR(DEG,PORT+)	1.4	-5.6	-2.2	-13.4(5.5639)	18.7(6.0037)
FLANK RUDDR(DEG,PORT+)	.3	.3	.4	.1(5.5644)	1.0(6.0018)
DRIFT(DEG,RES+ON PORT)	.9063	-1.3511	.7962	-18.5096(5.5758)	16.8781(5.5820)
YAW RATE(DEG/SECOND)	.0598	-.0074	.0013	-.8999(5.5815)	.3659(6.0204)
YAW ACCEL(DEG/SEC/SEC)	.0081	-.0017	-.0001	-.0602(5.5806)	.0889(5.5827)
XY ACCEL(FT/SEC/SEC)	.1181	.0398	.1332	.0021(6.0419)	.6693(5.5750)
DEPTH AT BOW(FEET)	47.0	45.2	50.3	44.4(6.0409)	60.0(6.0000)
DEPTH AT STERN(FEET)	46.0	51.1	49.0	43.1(6.0305)	55.0(5.5900)
DIST. OFF W.BANK(FEET)	1056.2	1075.5	1082.2	987.4(6.0115)	1158.3(5.5900)
E.BANK(FEET)	1495.9	1877.6	1418.0	1114.2(5.5821)	1877.6(6.0447)

* Engine RPM's had already started downward preparing for crash stop.

VIII. SPEED - POWER TESTS

This section of the report contains summary performance statistics from the straight course runs performed on the EXXON NASHVILLE and EXXON LAKE CHARLES. These runs were designed to measure the speed-power performance of the Exxon tows over a measured straight river course. The trial course (described in Section 3.1) was composed of range markers along the west bank of the river, about 1 mile apart, separating the course into north/south legs.

The tests noted the time when the pilothouse was abeam each range mark. Because the distance separating each of the ranges was known, tow speed over the course could be calculated. Tables 8.A through 8.P in this section give the X, Y coordinates of the pilothouse Miniranger antenna when the tow was abeam these marks. The positions of the bow antenna and center of gravity as well as the distance traveled were also given.

There are tables for each straight course test run made by the EXXON NASHVILLE and EXXON LAKE CHARLES over each south and north leg of the course. The tables contain the differentiated values for tow velocity, acceleration, and angular motion as well as river depth, width, and power data. Velocity is given both as speed over the ground and through the water. Speed through the water is obtained by subtracting the appropriate $\dot{X}$, $\dot{Y}$ current values from Section 3.3. from the computed speed over the ground. The average values for velocity, RPM, SHP, and so forth, are the summed values recorded for the tow each second during the transit of a particular leg divided by the total seconds of the run.

8.1 EXXON NASHVILLE Tests

Table 8.A and 8.B list the EXXON NASHVILLE's full power upstream performance data over the south and north leg of the course, respectively. The average speed over the ground and through the water indi-

cate that a current of about 3.1 mph was running. The tow's average speed was between 11.9 and 12.1 mph with relatively little rudder used for steering. Average horsepower used was 3319 and 3327 respectively. From Appendix E, diesel oil consumption was 295 pounds over both legs yielding an average of 0.38 pounds per SHP-Hour. The instantaneous drift angle was a moderate ± 3 degrees over the south leg and a relatively high -28 to 11 degrees over the north leg. This high drift angle could be due in part to positioning errors, but the minimum and maximum values for rudder usage also increased.

Tables 8.C and 8.D list the EXXON NASHVILLE's performance at full power downstream over the course. Average velocity through the water was 10.7 and 11.2 mph over the north and south legs of the course. Average SHP was 3314 and 3329 over each leg for a total fuel consumption of 185 pounds at a specific fuel consumption rate of 0.38 pounds per SHP-Hour. A river current of about 3.1 mph is included in Tables 8.A through 8.D and caused a spread of about 1.0 mph between upstream and downstream tow velocities through water. This indicates that current velocity measurements may be about 0.5 mph higher than the current experienced by the tow. As in Run 1, the drift angles recorded over the north leg were much higher than those over the south leg of the course. Rudder usage was negligible.

Tables 8.E and 8.F show the upstream performance of the EXXON NASHVILLE at 3/4 power during Run 3. Speed averaged 11.1 and 11.0 mph over each leg at 2571 and 2574 SHP, respectively, with specific fuel consumption at 0.37 pounds per SHP-Hour. The large minimum and maximum drift angles over the north leg are due in part to position measurement variations, although moderate steering rudder activity was required.

Tables 8.G and 8.H give the downstream Run 4 half power perform-

ance of the EXXON NASHVILLE. Tow speed through the water averaged 8.1 and 8.5 mph over the north and south legs of the course, respectively. Tow horsepower averaged 1453 and 1434 over the two legs yielding a specific fuel consumption value of 0.40 pounds per SHP-Hour for the run. The minimum and maximum drift angle assumed by the tow over the north leg were large ($\pm$21 degrees). These values appear reasonable, however, with the tow moving at half power ahead of a brisk current. Rudder usage was moderate on both legs, although significantly greater than on the previous 3 runs.

Runs 1 through 4 showed that the tow's port and starboard engines had SHP differences from 5 to 13 percent greater on the port engine. This imbalance was consistantly reflected in the average rudder angles employed in which 1 to 3 degrees of port steering rudder were consistantly used.

8.2 EXXON LAKE CHARLES Tests

The EXXON LAKE CHARLES tests are similar in form to the previously described EXXON NASHVILLE tests and are listed in Tables 8.I through 8.P at the end of this section. There are 4 test runs tabulated in which each run is separated into north and south legs for listing tow performance.

Tables 8.I and 8.J give the characteristics obtained from the EXXON LAKE CHARLES upstream full power Run 1 over the straight course. The tow averaged 10.7 and 10.6 mph through the water over the south and north legs at 2357 and 2352 SHP, respectively. Little rudder was used and moderate instantaneous drift angles were observed. Fuel consumption was 250 pounds for a specific fuel consumption rate of 0.39 pounds per SHP-Hour.

Tables 8.K and 8.L list the downstream full power performance of

the tow in which average speed through the water was 10.0 and 10.5 over the north and south legs of the course. Fuel consumption was 143 pounds with the engines averaging 2398 and 2360 over the course for a specific fuel consumption rate of 0.39 pounds per SHP-Hour. Little rudder was used over both legs and drift angles and yaw rates were moderate.

Tables 8.M and 8.N list the Run 3,3/4 power upstream performance of the tow. Average speed through the water was 9.6 mph over both legs, SHP averaging 1748 and 1755 over the south and north legs of the course, respectively. Fuel consumption of 211 pounds gave a specific fuel consumption rate of 0.387 pounds per SHP-Hour. Rudder usage was light and the instantaneous drift angles and yaw rates were moderate.

Tables 8.O and 8.P give the EXXON LAKE CHARLES downstream Run 4 performance at half power. Average speed was 7.7 and 8.0 mph using 1117 and 1109 SHP over the north and south legs of the course, respectively. The specific fuel consumption rate was 0.40 pounds per SHP-Hour based on 84 pounds of fuel being consumed. Rudder usage increased considerably over the other test runs as was expected during downstream low-power operation. Drift angles and yaw rates were also relatively large over the north leg.

Runs 1 and 2 (Tables 8.I through 8.L) show that port and starboard engines generated between 5 and 8 percent different powers. During runs 3 and 4 (Tables 8.M through 8.P) port and starboard engine SHP was nearly the same.

8.3 Speed Power Comparisons

Figure 8.a shows the speed-power performance data plotted from Tables 8.A-8.P for the south leg only. These points show the variations obtained even in a reasonably well controlled river tow test. The study was to compare the performances of the Kort nozzle and open-wheel tows. The EXXON MEMPHIS, a Kort nozzle towboat tested Nov-

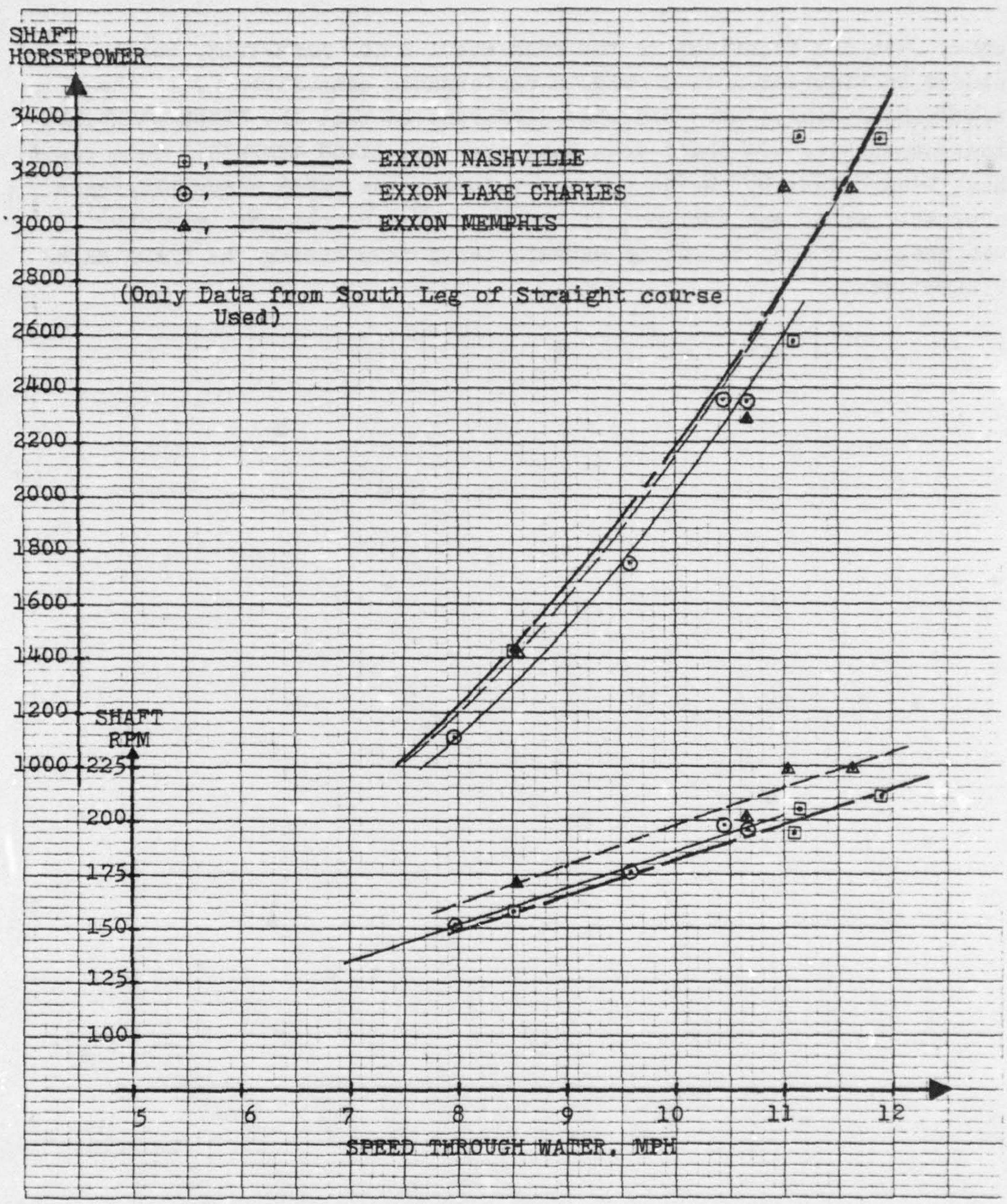

Figure 8.a Speed-Power Curves

ember 1976 and identical to the open-wheel EXXON NASHVILLE, was included in Figure 8.a to provide a performance comparison [1]. The test circumstances were somewhat different in that the EXXON NASHVILLE tow was pushing 474 short tons more than the EXXON MEMPHIS. This could have been offset by the deeper water during the EXXON NASHVILLE tests, however. Also, the port and starboard engine horsepower imbalance was greater during the EXXON MEMPHIS tests than during the EXXON NASHVILLE tests.

Table 8.A

EXXON NASHVILLE - Upstream Run 1

Full Power Run Over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=14.2718 END =14.3426 TOTAL SECONDS= 429

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52818.0	42766.1	58384.8	42778.8	5566.8	5568.5
BOW ANTENNA	53857.6	42775.9	59418.5	42801.4	5561.0	5564.8
CENT. GRAV.	53335.2	42771.5	58901.6	42790.7	5566.5	5567.6

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	12.7021	12.8967	13.0081	12.6524(14.3345)	13.8916(14.3158)
(MPH)	8.6605	8.7932	8.8692	8.6266(14.3345)	9.4716(14.3158)
VELOCITY T.W.(FPS)	16.1245	17.9083	17.4390	16.1245(14.2718)	18.6428(14.3158)
(MPH)	10.9939	12.2102	11.8902	10.9939(14.2718)	12.7110(14.3158)
PORT ENGINE SHP	1713.4	1711.7	1710.5	1705.5(14.2930)	1713.6(14.3342)
SHAFT RPM	212.4	212.4	213.9	212.1(14.2721)	228.3(14.2901)
STBD ENGINE SHP	1599.3	1618.8	1608.7	1599.1(14.2739)	1618.8(14.3426)
SHAFT RPM	216.6	201.9	210.8	200.2(14.3407)	242.4(14.2858)
BOTH ENGINE SHP	3312.8	3330.5	3319.2	3309.4(14.2847)	3330.5(14.3426)
AVE. SHAFT RPM	214.5	207.1	212.3	206.4(14.3407)	233.1(14.2858)
STEER RUDDR(DEG,PORT+)	4.4	8.9	2.4	-3.1(14.2947)	9.4(14.3149)
FLANK RUDDR(DEG,PORT+)	.2	.4	.6	.2(14.2718)	3.5(14.2913)
DRIFT(DEG,RES+ON PORT)	-1.0619	-.4048	.7162	-2.9338(14.2955)	3.1730(14.3253)
YAW RATE(DEG/SECOND)	.0184	-.0036	.0016	-.0771(14.2905)	.0792(14.2847)
YAW ACCEL(DEG/SEC/SEC)	.0029	.0080	-.0000	-.0180(14.2856)	.0158(14.3058)
XY ACCEL(FT/SEC/SEC)	.0498	.0800	.0561	.0018(14.3138)	.1525(14.3003)
DEPTH AT BOW(FEET)	40.5	55.2	49.2	40.5(14.2718)	56.0(14.3402)
DEPTH AT STERN(FEET)	36.2	50.9	50.5	36.2(14.2718)	56.0(14.3232)
DIST. OFF W.BANK(FEET)	1289.8	882.4	1013.7	874.5(14.3342)	1289.8(14.2718)
E.BANK(FEET)	1623.4	1374.7	1528.7	1374.7(14.3426)	1623.4(14.2718)

Table 8.B

EXXON NASHVILLE - Upstream Run 1

Full Power Run over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=14.3426 END =14.4112 TOTAL SECONDS= 407

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58384.8	42778.8	63618.8	42619.1	5236.4	5351.2
BOW ANTENNA	59418.5	42801.4	64672.9	42506.9	5262.6	5280.7
CENT. GRAV.	58901.6	42790.7	64133.0	42565.1	5236.2	5271.5

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	12.8967	12.6155	12.9830	9.6722(14.3910)	17.3307(14.3934)
(MPH)	8.7932	8.6015	8.8520	6.5947(14.3910)	11.8164(14.3934)
VELOCITY T.W.(FPS)	17.9083	16.8134	17.7605	14.1472(14.3953)	21.7288(14.3934)
(MPH)	12.2102	11.4637	12.1094	9.6458(14.3953)	14.8151(14.3934)
PORT ENGINE SHP	1711.7	1704.0	1702.7	1697.0(14.3840)	1711.7(14.3426)
SHAFT RPM	212.4	212.8	215.2	204.3(14.3921)	236.6(14.3857)
STBD ENGINE SHP	1618.8	1628.1	1623.9	1618.8(14.3426)	1628.2(14.3956)
SHAFT RPM	201.9	194.5	199.0	188.6(14.4056)	226.6(14.3858)
BOTH ENGINE SHP	3330.5	3332.1	3326.6	3319.9(14.3806)	3332.1(14.3507)
AVE. SHAFT RPM	207.1	203.7	207.1	200.7(14.4056)	230.9(14.3857)
STEER RUDDR(DEG.PORT+)	8.9	3.1	2.5	-7.0(14.3444)	12.9(14.380[illegible])
FLANK RUDDR(DEG.PORT+)	.4	.3	.5	-.9(14.3937)	2.3(14.3943)
DRIFT(DEG.RES+ON PORT)	-.4048	.1902	-.7905	-28.1664(14.3912)	10.8415(14.3935)
YAW RATE(DEG/SECOND)	-.0036	-.0518	-.0181	-.5158(14.3908)	.3434(14.3934)
YAW ACCEL(DEG/SEC/SEC)	.0080	-.0089	-.0001	-.0622(14.3946)	.0580(14.4003)
XY ACCEL(FT/SEC/SEC)	.0800	.1520	.1732	.0088(14.3827)	.9233(14.3944)*
DEPTH AT BOW(FEET)	55.2	39.4	46.6	39.4(14.4112)	55.2(14.3426)
DEPTH AT STERN(FEET)	50.9	37.3	44.2	37.3(14.4112)	50.9(14.3426)
DIST. OFF W.BANK(FEET)	882.4	864.0	941.0	864.0(14.4112)	1000.3(14.3853)
E.BANK(FEET)	1374.7	1738.1	1450.8	1308.6(14.3604)	1738.1(14.4112)

* Probably caused by position measurement errors.

Table 8.C

EXXON NASHVILLE - Downstream Run 2

Full Power Run Over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS)   START=15.5548   END =16.0005   TOTAL SECONDS= 258

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	63556.4	42706.7	58370.5	42642.3	5186.3	5275.0
BOW ANTENNA	62533.7	42836.4	57321.9	42662.8	5214.7	5240.5
CENT. GRAV.	63043.1	42770.8	57852.4	42651.7	5192.0	5224.3

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	21.9073	21.0685	20.3321	18.1310(15.5606)	21.9075(15.5837)
(MPH)	14.9368	14.3649	13.8628	12.3620(15.5606)	14.9369(15.5837)
VELOCITY T.W.(FPS)	17.5067	16.4533	15.7214	13.5131(15.5606)	17.5067(15.5548)
(MPH)	11.9364	11.2182	10.7192	9.2135(15.5606)	11.9364(15.5548)
PORT ENGINE SHP	1733.1	1725.7	1724.0	1718.7(15.5810)	1733.1(15.5548)
SHAFT RPM	210.2	211.5	214.2	210.1(15.5707)	235.8(15.5628)
STBD ENGINE SHP	1576.1	1599.3	1589.9	1576.1(15.5548)	1599.3(16.0005)
SHAFT RPM	199.6	193.4	204.7	191.3(15.5855)	236.1(15.5628)
BOTH ENGINE SHP	3309.1	3325.0	3313.9	3308.5(15.5731)	3325.0(16.0005)
AVE. SHAFT RPM	204.9	202.4	209.5	201.3(15.5854)	235.9(15.5628)
STEER RUDDR(DEG,PORT+)	-.0	.0	.9	-2.4(15.5555)	3.0(15.5810)
FLANK RUDDR(DEG,PORT+)	.7	.8	.8	.4(15.5755)	1.0(15.5804)
DRIFT(DEG.RES+ON PORT)	-20.0632	-.0347	-2.4802	-20.1987(15.5549)	29.7773(15.5600)
YAW RATE(DEG/SECOND)	.5759	-.0368	-.0222	-.8843(15.5555)	.5759(15.5548)
YAW ACCEL(DEG/SEC/SEC)	-.3163	.0100	-.0029	-.3460(15.5550)	.1351(15.5559)
XY ACCEL(FT/SEC/SEC)	.1288	.3983	.3215	.0000(15.5700)	2.4612(15.5605)*
DEPTH AT BOW(FEET)	42.4	60.8	48.7	42.4(15.5548)	60.8(16.0005)
DEPTH AT STERN(FEET)	42.3	55.9	50.0	41.5(15.5624)	60.0(15.5921)
DIST. OFF W.BANK(FEET)	1061.5	744.1	849.0	721.8(15.5921)	1061.5(15.5548)
E.BANK(FEET)	1479.7	1614.3	1479.2	1400.3(15.5723)	1614.3(16.0005)

* Probably caused by position measurement errors.

Table 8.D

EXXON NASHVILLE - Downstream Run 2

Full Power Run Over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=16.0005 END =16.0432 TOTAL SECONDS= 268

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58370.5	42642.3	52804.1	42609.5	5566.5	5568.1
BOW ANTENNA	57321.9	42662.8	51758.2	42660.8	5563.7	5570.3
CENT. GRAV.	57852.4	42651.7	52288.4	42634.3	5564.0	5565.7

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	21.0685	20.6108	20.8452	18.9450(16.0104)	22.0041(16.0243)
(MPH)	14.3649	14.0528	14.2127	12.9170(16.0104)	15.0028(16.0243)
VELOCITY T.W.(FPS)	16.4533	16.2449	16.3533	14.3831(16.0104)	17.5296(16.0243)
(MPH)	11.2182	11.0761	11.1500	9.8066(16.0104)	11.9520(16.0243)
PORT ENGINE SHP	1725.7	1725.8	1722.8	1719.1(16.0237)	1726.8(16.0025)
SHAFT RPM	211.5	211.7	211.5	209.1(16.0400)	213.0(16.0255)
STBD ENGINE SHP	1599.3	1612.2	1605.9	1598.3(16.0059)	1615.1(16.0349)
SHAFT RPM	193.4	196.5	198.6	192.7(16.0322)	204.6(16.0118)
BOTH ENGINE SHP	3325.0	3338.0	3328.8	3322.1(16.0131)	3339.0(16.0408)
AVE. SHAFT RPM	202.4	204.1	205.0	202.2(16.0322)	208.4(16.0114)
STEER RUDDR(DEG,PORT+)	.0	4.2	1.4	-1.7(16.0245)	5.8(16.0034)
FLANK RUDDR(DEG,PORT+)	.8	.8	.8	.6(16.0355)	.9(16.0316)
DRIFT(DEG,RES+ON PORT)	-.0347	-2.3482	-1.9953	-7.3214(16.0035)	3.7265(16.0026)
YAW RATE(DEG/SECOND)	-.0368	.0199	.0062	-.3150(16.0035)	.1896(16.0027)
YAW ACCEL(DEG/SEC/SEC)	.0100	.0020	.0002	-.1059(16.0034)	.0606(16.0041)
XY ACCEL(FT/SEC/SEC)	.3983	.3559	.2397	.0235(16.0230)	.8903(16.0031) *
DEPTH AT BOW(FEET)	60.8	43.9	49.9	42.7(16.0353)	61.0(16.0015)
DEPTH AT STERN(FEET)	55.9	49.3	47.0	42.2(16.0259)	55.9(16.0005)
DIST. OFF W.BANK(FEET)	744.1	1088.0	941.6	744.1(16.0005)	1089.5(16.0420)
E.BANK(FEET)	1614.3	1887.0	1730.1	1614.3(16.0005)	1887.0(16.0432)

* Probably caused by position measurement errors.

Table 8.E

EXXON NASHVILLE - Upstream Run 3

3/4 Power Run Over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=17.1212 END =17.2013 TOTAL SECONDS= 482

COORDINATES(FEET):	X,START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52799.8	42558.3	58381.7	42454.6	5583.0	5600.3
BOW ANTENNA	53835.0	42558.4	59402.1	42479.8	5567.8	5588.2
CENT. GRAV.	53317.1	42558.3	58899.1	42468.3	5582.6	5590.1

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	11.7508	11.9279	11.6223	10.6180(17.1326)	12.7076(17.1310)
(MPH)	8.0119	8.1327	7.9243	7.2396(17.1326)	8.6643(17.1310)
VELOCITY T.W.(FPS)	16.6344	16.3231	16.2650	15.4244(17.1326)	17.5198(17.1310)
(MPH)	11.3416	11.1294	11.0898	10.5166(17.1326)	11.9453(17.1310)
PORT ENGINE SHP	1397.6	1383.3	1378.2	1360.7(17.1417)	1397.6(17.1212)
SHAFT RPM	197.5	198.8	199.0	196.5(17.1814)	230.1(17.1707)
STBD ENGINE SHP	1212.2	1185.6	1193.0	1183.4(17.1938)	1212.2(17.1212)
SHAFT RPM	192.8	185.3	189.7	184.4(17.1822)	203.7(17.1648)
BOTH ENGINE SHP	2609.8	2568.9	2571.2	2558.9(17.1435)	2609.8(17.1212)
AVE. SHAFT RPM	195.1	192.1	194.4	190.8(17.1822)	213.4(17.1707)
STEER RUDDR(DEG,PORT+)	-.1	1.1	2.8	-2.2(17.1413)	15.5(17.1952)
FLANK RUDDR(DEG,PORT+)	-1.6	-2.0	-1.8	-2.8(17.1714)	-1.5(17.1224)
DRIFT(DEG,RES+ON PORT)	2.6249	-3.7913	2.4536	-6.3263(17.1954)	11.7910(17.2005)
YAW RATE(DEG/SECOND)	.0529	-.1096	.0029	-.2053(17.1934)	.2116(17.1613)
YAW ACCEL(DEG/SEC/SEC)	-.0099	.0752	-.0002	-.1471(17.1910)	.1290(17.1903)
XY ACCEL(FT/SEC/SEC)	.2000	.1659	.1554	.0022(17.1543)	.6246(17.2000)
DEPTH AT BOW(FEET)	46.9	59.2	52.8	46.9(17.1212)	60.0(17.1941)
DEPTH AT STERN(FEET)	27.3	53.2	51.1	27.3(17.1212)	60.0(17.1813)
DIST. OFF W.BANK(FEET)	1375.7	531.4	794.5	525.0(17.1923)	1375.7(17.1212)
E.BANK(FEET)	1833.4	1726.6	1837.2	1726.6(17.2013)	1867.2(17.1505)

Table 8.F

EXXON NASHVILLE - Upstream Run 3

3/4 Power Run Over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=17.2013 END =17.2741 TOTAL SECONDS= 449

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58381.7	42454.6	63536.5	42699.1	5160.5	5903.0
BOW ANTENNA	59402.1	42479.8	64636.6	42590.5	5235.5	5263.5
CENT. GRAV.	58899.1	42468.3	64051.4	42648.3	5155.5	5409.4

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	11.9279	12.3857	12.0738	8.8905(17.2642)	20.2621(17.2547)
(MPH)	8.1327	8.4448	8.2322	6.0617(17.2642)	13.8150(17.2547)
VELOCITY T.W.(FPS)	16.3231	16.4617	16.1567	11.7576(17.2637)	24.2143(17.2547)
(MPH)	11.1294	11.2239	11.0159	8.0165(17.2637)	16.5097(17.2547)
PORT ENGINE SHP	1383.3	1381.6	1378.3	1366.8(17.2322)	1387.7(17.2545)
SHAFT RPM	198.8	198.4	199.8	196.9(17.2106)	215.3(17.2534)
STBD ENGINE SHP	1185.6	1202.1	1195.8	1185.6(17.2013)	1202.1(17.2741)
SHAFT RPM	185.3	181.8	192.1	181.6(17.2738)	227.0(17.2637)
BOTH ENGINE SHP	2568.9	2583.7	2574.1	2563.8(17.2329)	2584.2(17.2545)
AVE. SHAFT RPM	192.1	190.1	195.9	189.9(17.2738)	217.9(17.2534)
STEER RUDDR(DEG,PORT+)	1.1	5.9	2.0	-5.8(17.2052)	9.9(17.2348)
FLANK RUDDR(DEG,PORT+)	-2.0	-2.0	-1.8	-2.8(17.2519)	-1.4(17.2320)
DRIFT(DEG,RES+ON PORT)	-3.7913	-2.7987	-.8572	-85.6454(17.2633)*	51.7348(17.2558)*
YAW RATE(DEG/SECOND)	-.1096	-.0509	-.0159	-1.7251(17.2629)	1.2177(17.2557)
YAW ACCEL(DEG/SEC/SEC)	.0752	-.0055	.0002	-.1748(17.2515)	.2367(17.2522)
XY ACCEL(FT/SEC/SEC)	.1659	.1984	.2515	.0023(17.2734)	1.3721(17.2608)*
DEPTH AT BOW(FEET)	59.2	39.0	48.3	39.0(17.2741)	59.2(17.2013)
DEPTH AT STERN(FEET)	53.2	35.8	41.6	35.6(17.2700)	53.2(17.2013)
DIST. OFF W.BANK(FEET)	531.4	943.8	757.9	531.4(17.2013)	945.3(17.2721)
E.BANK(FEET)	1726.6	1651.1	1649.3	1627.8(17.2509)	1726.6(17.2013)

* Probably due to position measurement errors.

Table 8.G

EXXON NASHVILLE - Downstream Run 4

Half Power Run Over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=19.1327 END =19.1846 TOTAL SECONDS= 320

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	63518.5	42429.6	58386.5	42465.4	5132.2	5237.0
BOW ANTENNA	62589.2	42321.3	57367.7	42504.4	5224.9	5259.8
CENT. GRAV.	63004.9	42368.6	57869.6	42484.6	5136.6	5149.9

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	14.9246	17.5866	16.1439	5.3086(19.1430)	18.3013(19.1606)
(MPH)	10.1758	11.9909	11.0072	3.6195(19.1430)	12.4781(19.1606)
VELOCITY T.W.(FPS)	11.0263	13.0532	11.8529	1.2736(19.1430)	13.9684(19.1606)
(MPH)	7.5179	8.8999	8.0815	.8684(19.1430)	9.5239(19.1606)
PORT ENGINE SHP	766.4	767.5	768.0	766.3(19.1329)	768.6(19.1707)
SHAFT RPM	161.2	161.8	163.5	160.0(19.1542)	182.8(19.1449)
STBD ENGINE SHP	692.2	676.5	684.9	676.5(19.1846)	696.3(19.1419)
SHAFT RPM	159.5	156.5	159.0	146.9(19.1645)	189.2(19.1457)
BOTH ENGINE SHP	1458.6	1444.0	1452.9	1444.0(19.1846)	1463.6(19.1425)
AVE. SHAFT RPM	160.4	159.1	161.2	154.3(19.1644)	183.5(19.1452)
STEER RUDDR(DEG.PORT+)	-.8	6.2	1.2	-6.7(19.1419)	10.5(19.1349)
FLANK RUDDR(DEG.PORT+)	-1.9	-1.9	-1.6	-2.1(19.1459)	-.6(19.1434)
DRIFT(DEG.RES+ON PORT)	6.7021	-.3309	-.6497	-21.3208(19.1435)	21.2267(19.1408)
YAW RATE(DEG/SECOND)	.0978	.1029	.0279	-.2517(19.1355)	1.5329(19.1429)
YAW ACCEL(DEG/SEC/SEC)	-.0204	.0007	-.0000	-.7591(19.1433)*	.9947(19.1426)*
XY ACCEL(FT/SEC/SEC)	.2197	.0393	.2586	.0028(19.1455)	2.6784(19.1426)*
DEPTH AT BOW(FEET)	33.9	59.8	46.1	33.9(19.1327)	59.8(19.1846)
DEPTH AT STERN(FEET)	36.9	55.2	50.6	36.9(19.1327)	59.0(19.1800)
DIST. OFF W.BANK(FEET)	546.0	569.4	552.2	526.5(19.1734)	572.5(19.1521)
E.BANK(FEET)	1988.5	1784.6	1772.8	1695.6(19.1630)	1988.5(19.1327)

* Probably caused by position measurement errors.

Table 8.H

EXXON NASHVILLE - Downstream Run 4

Half Power Run Over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=19.1846 END =19.2416 TOTAL SECONDS= 331

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58386.5	42465.4	52772.6	42344.4	5615.1	5619.4
BOW ANTENNA	57367.7	42504.4	51776.8	42365.5	5592.5	5597.9
CENT. GRAV.	57869.6	42484.6	52256.2	42354.9	5615.0	5617.5

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	17.5866	17.7097	17.0243	15.7020(19.2009)	18.6076(19.2256)
(MPH)	11.9909	12.0748	11.6075	10.7059(19.2009)	12.6870(19.2256)
VELOCITY T.W.(FPS)	13.0532	13.2262	12.4960	11.1425(19.2009)	14.1055(19.2256)
(MPH)	8.8999	9.0178	8.5200	7.5971(19.2009)	9.6174(19.2256)
PORT ENGINE SHP	767.5	764.3	765.1	763.6(19.2243)	767.5(19.1846)
SHAFT RPM	161.8	161.9	161.3	150.7(19.2225)	168.4(19.2140)
STBD ENGINE SHP	676.5	639.9	668.5	639.9(19.2416)	680.3(19.2056)
SHAFT RPM	156.5	149.4	153.8	146.5(19.2250)	165.4(19.2141)
BOTH ENGINE SHP	1444.0	1404.2	1433.5	1404.2(19.2416)	1445.6(19.2051)
AVE. SHAFT RPM	159.1	155.6	157.5	151.3(19.2246)	166.4(19.2140)
STEER RUDDR(DEG,PORT+)	6.2	3.1	1.7	-9.0(19.2033)	9.9(19.2239)
FLANK RUDDR(DEG,PORT+)	-1.9	-2.0	-1.7	-2.1(19.2400)	-1.1(19.2123)
DRIFT(DEG,RES+ON PORT)	-.3309	-.9734	-1.8176	-7.3426(19.1856)	1.7637(19.2216)
YAW RATE(DEG/SECOND)	.1029	.0650	-.0026	-.1176(19.2054)	.1306(19.2250)
YAW ACCEL(DEG/SEC/SEC)	.0007	.0042	-.0001	-.0821(19.2123)	.0769(19.2116)
XY ACCEL(FT/SEC/SEC)	.0393	.2897	.1504	.0072(19.2326)	.3556(19.2302)
DEPTH AT BOW(FEET)	59.8	52.1	52.9	50.0(19.2130)	60.0(19.1900)
DEPTH AT STERN(FEET)	55.2	51.5	50.6	49.3(19.2145)	55.2(19.1846)
DIST. OFF W.BANK(FEET)	569.4	824.8	750.6	569.4(19.1846)	833.4(19.2327)
E.BANK(FEET)	1784.6	2116.2	1911.1	1784.6(19.1846)	2116.2(19.2416)

Table 8.I

EXXON LAKE CHARLES - Upstream Run 1

Full Power Run Over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START=22.3209 END =22.4032 TOTAL SECONDS= 504

COORDINATES(FEET):	X.START	Y.START	X.END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52856.8	42470.8	58407.7	42371.8	5551.8	5554.5
BOW ANTENNA	53886.6	42468.8	59438.3	42388.5	5552.3	5554.9
CENT. GRAV.	53364.8	42469.9	58916.0	42380.1	5551.9	5553.5

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	10.9898	11.1741	11.0409	10.6793(22.3831)	11.3662(22.3841)
(MPH)	7.4931	7.6187	7.5279	7.2814(22.3831)	7.7497(22.3841)
VELOCITY T.W.(FPS)	15.6461	15.6603	15.6595	15.2456(22.3831)	16.0283(22.3411)
(MPH)	10.6678	10.6775	10.6769	10.3947(22.3831)	10.9284(22.3411)
PORT ENGINE SHP	1233.5	1224.3	1220.4	1206.9(22.3540)	1238.7(22.3835)
SHAFT RPM	197.1	197.0	197.7	196.1(22.3841)	200.8(22.3410)
STBD ENGINE SHP	1128.5	1140.9	1136.4	1128.5(22.3209)	1142.4(22.3951)
SHAFT RPM	193.2	192.6	193.1	190.4(22.3305)	196.9(22.3455)
BOTH ENGINE SHP	2362.0	2365.2	2356.9	2341.8(22.3352)	2378.1(22.3835)
AVE. SHAFT RPM	195.2	194.8	195.4	194.0(22.3351)	197.9(22.3417)
STEER RUDDR(DEG.PORT+)	.6	.5	-.3	-4.9(22.3228)	6.6(22.3827)
FLANK RUDDR(DEG,PORT+)	-.7	-1.0	-.7	-1.0(22.4014)	-.3(22.3555)
DRIFT(DEG,RES+ON PORT)	.3288	.8762	1.3126	-1.1094(22.4019)	3.9875(22.3806)
YAW RATE(DEG/SECOND)	.0021	.0040	.0020	-.0492(22.3542)	.0766(22.3757)
YAW ACCEL(DEG/SEC/SEC)	-.0043	.0038	.0000	-.0143(22.3804)	.0120(22.3816)
XY ACCEL(FT/SEC/SEC)	.0917	.0613	.0457	.0011(22.3652)	.1514(22.3836)
DEPTH AT BOW(FEET)	49.9	60.5	56.1	49.9(22.3209)	62.3(22.3934)
DEPTH AT STERN(FEET)	52.9	53.9	55.9	52.4(22.3330)	60.2(22.3811)
DIST. OFF W.BANK(FEET)	808.3	484.9	609.4	459.4(22.3851)	808.3(22.3209)
E.BANK(FEET)	1943.0	1768.3	1911.1	1768.3(22.4032)	1943.1(22.3223)

Table 8.J

EXXON LAKE CHARLES - Upstream Run 1

Full Power Run Over North Leg og Straight Course

SUMMARY TIMES(HH.MMSS) START=22.4032 END =22.4815 TOTAL SECONDS= 464

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58407.7	42371.8	63656.6	42369.3	5248.9	5269.0
BOW ANTENNA	59438.3	42388.5	64686.0	42351.5	5247.8	5263.1
CENT. GRAV.	58916.0	42380.1	64164.4	42360.7	5248.4	5257.0

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	11.1741	11.4563	11.3541	10.8198(22.4153)	12.5476(22.4806)
(MPH)	7.6187	7.8111	7.7414	7.3772(22.4153)	8.5552(22.4806)
VELOCITY T.W.(FPS)	15.6603	15.2834	15.5174	14.7757(22.4736)	16.3864(22.4806)
(MPH)	10.6775	10.4205	10.5800	10.0743(22.4736)	11.1725(22.4806)
PORT ENGINE SHP	1224.3	1193.0	1210.4	1193.0(22.4815)	1224.3(22.4032)
SHAFT RPM	197.0	195.8	197.6	195.5(22.4801)	202.4(22.4424)
STBD ENGINE SHP	1140.9	1143.3	1141.0	1136.8(22.4220)	1143.3(22.4815)
SHAFT RPM	192.6	192.0	191.8	187.8(22.4609)	199.8(22.4425)
BOTH ENGINE SHP	2365.2	2336.3	2351.5	2336.3(22.4815)	2365.2(22.4032)
AVE. SHAFT RPM	194.8	193.9	194.7	192.5(22.4613)	200.7(22.4424)
STEER RUDDR(DEG,PORT+)	.5	-1.5	-.5	-4.2(22.4513)	2.1(22.4119)
FLANK RUDDR(DEG,PORT+)	-1.0	-1.0	-.8	-1.1(22.4719)	-.3(22.4124)
DRIFT(DEG.RES+ON PORT)	.8762	.9039	.1789	-11.3893(22.4553)	11.4545(22.4537)
YAW RATE(DEG/SECOND)	.0040	.0202	-.0041	-.2346(22.4551)	.1884(22.4703)
YAW ACCEL(DEG/SEC/SEC)	.0038	-.0176	.0000	-.0537(22.4545)	.0386(22.4558)
XY ACCEL(FT/SEC/SEC)	.0613	.1900	.0896	.0024(22.4156)	.4775(22.4544)
DEPTH AT BOW(FEET)	60.5	33.4	45.4	33.4(22.4815)	60.5(22.4032)
DEPTH AT STERN(FEET)	53.9	33.4	40.7	33.4(22.4815)	53.9(22.4032)
DIST. OFF W.BANK(FEET)	484.9	650.4	592.9	484.9(22.4032)	650.4(22.4815)
E.BANK(FEET)	1768.3	1940.8	1793.6	1667.9(22.4230)	1940.8(22.4815)

Table 8.K

EXXON LAKE CHARLES - Downstream Run 2

Full Power Run over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= .1319 END = .1746 TOTAL SECONDS= 268

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	63644.0	42444.0	58570.2	42570.5	5075.2	5080.1
BOW ANTENNA	62613.4	42450.8	57531.3	42611.5	5084.7	5132.6
CENT. GRAV.	63135.4	42447.4	58062.4	42590.5	5074.9	5089.1

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	17.6596	19.2987	19.0575	17.6307(.1348)	21.3220(.1637)
(MPH)	12.0406	13.1582	12.9938	12.0209(.1348)	14.5377(.1637)
VELOCITY T.W.(FPS)	13.2668	14.7766	14.6359	13.2475(.1348)	16.9885(.1637)
(MPH)	9.0455	10.0749	9.9790	9.0324(.1348)	11.5830(.1637)
PORT ENGINE SHP	1252.4	1242.8	1251.8	1242.8(.1746)	1255.9(.1521)
SHAFT RPM	199.4	199.2	199.4	196.5(.1433)	203.1(.1629)
STBD ENGINE SHP	1135.5	1150.2	1145.7	1135.5(.1319)	1150.2(.1746)
SHAFT RPM	193.4	192.8	193.8	191.1(.1423)	196.4(.1720)
BOTH ENGINE SHP	2388.0	2393.0	2397.5	2388.0(.1319)	2402.4(.1543)
AVE. SHAFT RPM	196.4	196.0	196.6	194.4(.1431)	199.1(.1631)
STEER RUDDR(DEG,PORT+)	.8	.0	-.6	-4.4(.1529)	4.1(.1331)
FLANK RUDDR(DEG,PORT+)	1.2	1.4	1.1	.9(.1421)	1.4(.1744)
DRIFT(DEG,RES+ON PORT)	.1043	-1.4175	1.3036	-5.8953(.1619)	22.0240(.1639)
YAW RATE(DEG/SECOND)	.0436	-.0223	.0070	-.3404(.1624)	.6418(.1643)
YAW ACCEL(DEG/SEC/SEC)	-.0172	.0084	-.0002	-.0710(.1646)	.1214(.1633)
XY ACCEL(FT/SEC/SEC)	.1825	.0129	.1562	.0063(.1523)	.8625(.1631)
DEPTH AT BOW(FEET)	34.0	62.3	46.0	34.0(.1319)	62.3(.1746)
DEPTH AT STERN(FEET)	36.8	58.3	51.5	36.8(.1319)	62.0(.1715)
DIST. OFF W.BANK(FEET)	697.8	667.5	667.9	643.7(.1651)	697.8(.1319)
E.BANK(FEET)	1828.1	1667.4	1659.3	1586.9(.1600)	1828.1(.1319)

Table 8.L

EXXON LAKE CHARLES - Downstream Run 2

Full Power Run over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= .1746 END = .2234 TOTAL SECONDS= 289

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58570.2	42570.5	52867.6	42562.8	5702.7	5703.6
BOW ANTENNA	57531.3	42611.5	51854.8	42562.8	5676.7	5677.2
CENT. GRAV.	58062.4	42590.5	52359.2	42562.8	5703.3	5703.5

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	19.2987	20.4809	19.8043	19.2979(.1821)	20.6226(.1937)
(MPH)	13.1582	13.9643	13.5029	13.1577(.1821)	14.0608(.1937)
VELOCITY T.W.(FPS)	14.7766	16.1374	15.3325	14.7687(.1821)	16.2159(.2152)
(MPH)	10.0749	11.0028	10.4540	10.0696(.1821)	11.0563(.2152)
PORT ENGINE SHP	1242.8	1174.9	1209.5	1174.9(.2230)	1242.8(.1746)
SHAFT RPM	199.2	200.1	199.7	197.1(.1958)	203.4(.2216)
STBD ENGINE SHP	1150.2	1150.7	1150.5	1150.2(.1746)	1150.7(.2229)
SHAFT RPM	192.8	199.5	195.4	190.7(.2138)	205.2(.2221)
BOTH ENGINE SHP	2393.0	2325.5	2359.9	2325.5(.2230)	2393.0(.1746)
AVE. SHAFT RPM	196.0	199.8	197.6	195.1(.2157)	203.5(.2216)
STEER RUDDR(DEG,PORT+)	.0	.9	-1.2	-8.3(.2154)	1.1(.2233)
FLANK RUDDR(DEG.PORT+)	1.4	2.0	1.7	1.2(.1803)	2.4(.2223)
DRIFT(DEG,RES+ON PORT)	-1.4175	-.1797	-1.5175	-3.0801(.2111)	-.1000(.2228)
YAW RATE(DEG/SECOND)	-.0223	-.0112	-.0078	-.0665(.2201)	.0533(.2108)
YAW ACCEL(DEG/SEC/SEC)	.0084	.0004	.0000	-.0108(.1959)	.0097(.1747)
XY ACCEL(FT/SEC/SEC)	.0129	.0737	.0615	.0016(.2132)	.1245(.2200)
DEPTH AT BOW(FEET)	62.3	52.1	53.7	50.0(.2015)	63.0(.1807)
DEPTH AT STERN(FEET)	58.3	52.3	50.1	46.5(.2054)	58.3(.1746)
DIST. OFF W.BANK(FEET)	667.5	1003.2	874.8	667.5(.1746)	1019.1(.2145)
E.BANK(FEET)	1667.4	1955.3	1773.3	1667.4(.1746)	1955.3(.2234)

Table 8.M

EXXON LAKE CHARLES - Upstream Run 3

3/4 Power Run over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= 1.3557 END = 1.4541 TOTAL SECONDS= 585

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52833.9	42650.8	58400.5	42487.6	5569.0	5576.3
BOW ANTENNA	53865.3	42634.8	59425.0	42472.1	5562.1	5567.4
CENT. GRAV.	53342.3	42642.9	58908.5	42479.9	5568.7	5571.1

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	9.8671	9.0254	9.5395	8.8541(1.4004)	10.2903(1.4146)
(MPH)	6.7276	6.1537	6.5042	6.0369(1.4004)	7.0161(1.4146)
VELOCITY T.W.(FPS)	14.4215	13.4579	14.0631	13.4033(1.4004)	14.8183(1.4146)
(MPH)	9.8329	9.1759	9.5885	9.1386(1.4004)	10.1034(1.4146)
PORT ENGINE SHP	870.0	872.7	872.8	862.1(1.4200)	886.2(1.3926)
SHAFT RPM	177.3	172.9	176.0	170.7(1.4000)	180.2(1.3902)
STBD ENGINE SHP	880.0	866.6	874.7	863.8(1.4047)	885.3(1.3809)
SHAFT RPM	175.5	175.9	176.8	172.9(1.4128)	180.9(1.3957)
BOTH ENGINE SHP	1750.0	1739.3	1747.5	1733.1(1.4140)	1764.4(1.3847)
AVE. SHAFT RPM	176.4	174.4	176.4	172.6(1.4131)	179.2(1.3902)
STEER RUDDR(DEG,PORT+)	-.4	1.4	-.9	-5.7(1.4217)	4.7(1.4345)
FLANK RUDDR(DEG,PORT+)	.0	-.2	.0	-.2(1.4537)	2.2(1.3838)
DRIFT(DEG,RES+ON PORT)	.6733	-1.1405	1.3928	-2.0882(1.3722)	7.3766(1.4255)
YAW RATE(DEG/SECOND)	-.0101	-.0849	-.0000	-.1162(1.4442)	.0714(1.3821)
YAW ACCEL(DEG/SEC/SEC)	.0007	.0008	-.0001	-.0208(1.4411)	.0210(1.4423)
XY ACCEL(FT/SEC/SEC)	.0882	.0388	.0727	.0039(1.4350)	.1890(1.3716)
DEPTH AT BOW(FEET)	46.0	58.8	52.0	46.0(1.3557)	60.0(1.4505)
DEPTH AT STERN(FEET)	49.1	54.2	54.3	48.7(1.3707)	60.0(1.4320)
DIST. OFF W.BANK(FEET)	991.6	569.2	762.2	561.3(1.4515)	992.6(1.3615)
E.BANK(FEET)	1766.3	1686.0	1761.1	1686.0(1.4541)	1784.1(1.4246)

Table 8.N

EXXON LAKE CHARLES - Upstream Run 3

3/4 Power Run over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= 1.4541 END = 1.5437 TOTAL SECONDS= 537

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58400.5	42487.6	63624.3	42374.3	5225.1	5252.9
BOW ANTENNA	59425.0	42472.1	64658.1	42372.6	5234.1	5285.3
CENT. GRAV.	58908.5	42479.9	64132.4	42373.6	5225.0	5243.6

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	9.0254	10.6555	9.7828	8.9820(1.4544)	10.6941(1.5315)
(MPH)	6.1537	7.2651	6.6701	6.1241(1.4544)	7.2914(1.5315)
VELOCITY T.W.(FPS)	13.4579	14.7488	14.0312	13.2466(1.5249)	14.7999(1.5315)
(MPH)	9.1759	10.0560	9.5667	9.0318(1.5249)	10.0909(1.5315)
PORT ENGINE SHP	872.7	880.9	874.3	872.4(1.4623)	880.9(1.5437)
SHAFT RPM	172.9	171.4	175.8	167.7(1.5157)	180.6(1.5254)
STBD ENGINE SHP	866.6	876.6	880.7	866.6(1.4541)	885.1(1.4952)
SHAFT RPM	175.9	178.8	176.3	172.2(1.5011)	179.4(1.5349)
BOTH ENGINE SHP	1739.3	1757.5	1755.0	1739.3(1.4541)	1760.1(1.4914)
AVE. SHAFT RPM	174.4	175.1	176.0	171.9(1.5157)	179.2(1.5126)
STEER RUDDR(DEG,PORT+)	1.4	.7	-1.3	-7.6(1.4701)	2.6(1.4803)
FLANK RUDDR(DEG,PORT+)	-.2	-.0	-.0	-.2(1.4549)	.2(1.4706)
DRIFT(DEG,RES+ON PORT)	-1.1405	1.8442	.7461	-16.1169(1.5157)	15.7799(1.5241)
YAW RATE(DEG/SECOND)	-.0849	.0543	.0014	-.2672(1.5124)	.2281(1.5221)
YAW ACCEL(DEG/SEC/SEC)	.0008	-.0107	.0002	-.0511(1.5319)	.0467(1.5138)
XY ACCEL(FT/SEC/SEC)	.0388	.0546	.1059	.0039(1.4801)	.4239(1.5149)
DEPTH AT BOW(FEET)	58.8	35.0	45.8	35.0(1.5330)	58.8(1.4541)
DEPTH AT STERN(FEET)	54.2	25.0	38.9	25.0(1.5330)	54.2(1.4541)
DIST. OFF W.BANK(FEET)	569.2	598.5	601.2	569.2(1.4541)	612.5(1.5039)
E.BANK(FEET)	1686.0	2082.5	1785.2	1625.4(1.4746)	2082.5(1.5330)

Table 8.0

EXXON LAKE CHARLES - Downstream Run 4

Half Power Run over North Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= 3.1936 END = 3.2514 TOTAL SECONDS= 339

COORDINATES(FEET):	X.START	Y.START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	63634.8	42431.7	58343.8	42479.6	5291.2	5317.6
BOW ANTENNA	62622.9	42449.9	57325.0	42525.0	5298.5	5387.6
CENT. GRAV.	63127.0	42440.5	57836.0	42502.2	5291.3	5282.2

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	15.1269	16.2052	15.6986	13.5826(3.1946)	17.9643(3.2343)
(MPh)	10.3138	11.0490	10.7036	9.2608(3.1946)	12.2484(3.2343)
VELOCITY T.W.(FPS)	10.8020	11.6496	11.3243	9.3790(3.1946)	13.5128(3.2343)
(MPH)	7.3650	7.9429	7.7211	6.3948(3.1946)	9.2133(3.2343)
PORT ENGINE SHP	585.5	559.6	568.4	558.6(3.2440)	585.5(3.1936)
SHAFT RPM	153.2	152.9	153.3	151.9(3.2029)	155.6(3.2153)
STBD ENGINE SHP	552.6	551.4	548.4	543.0(3.2131)	552.7(3.2327)
SHAFT RPM	149.9	151.1	151.5	149.9(3.2131)	153.5(3.2146)
BOTH ENGINE SHP	1138.1	1111.0	1116.8	1110.4(3.2440)	1138.1(3.1936)
AVE. SHAFT RPM	151.5	152.0	152.4	151.2(3.2033)	154.0(3.2202)
STEER RUDDR(DEG,PORT+)	-9.2	1.7	-1.1	-9.2(3.1936)	5.3(3.2223)
FLANK RUDDR(DEG,PORT+)	1.2	1.2	1.2	1.1(3.2337)	1.3(3.2228)
DRIFT(DEG,RES+ON PORT)	.9757	-2.1792	.1574	-18.0484(3.2327)	13.5554(3.2309)
YAW RATE(DEG/SECOND)	.0240	.0315	.0045	-.5984(3.2334)	.6766(3.2311)
YAW ACCEL(DEG/SEC/SEC)	.0249	-.0026	.0000	-.0967(3.2320)	.0714(3.2357)
XY ACCEL(FT/SEC/SEC)	.1920	.0181	.1309	.0023(3.2459)	.7484(3.2320)
DEPTH AT BOW(FEET)	38.3	59.8	47.6	38.3(3.1936)	59.8(3.2514)
DEPTH AT STERN(FEET)	46.8	57.8	52.8	45.8(3.2034)	61.0(3.2422)
DIST. OFF W.BANK(FEET)	670.8	584.2	598.3	551.8(3.2404)	670.8(3.1936)
E.BANK(FEET)	1834.8	1771.9	1719.6	1664.8(3.2233)	1834.8(3.1936)

Table 8.P

EXXON LAKE CHARLES - Downstream Run 4

Half Power Run over South Leg of Straight Course

SUMMARY TIMES(HH.MMSS) START= 3.2514 END = 3.3056 TOTAL SECONDS= 343

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	58343.8	42479.6	52817.4	42438.6	5526.5	5444.7
BOW ANTENNA	57325.0	42525.0	51798.4	42484.4	5526.8	5491.5
CENT. GRAV.	57836.0	42502.2	52309.7	42461.4	5526.5	5502.9

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	16.2052	16.2676	16.1609	15.2523(3.2930)	16.5583(3.2834)
(MPH)	11.0490	11.0915	11.0188	10.3993(3.2930)	11.2897(3.2834)
VELOCITY T.W.(FPS)	11.6496	11.9863	11.6953	10.9127(3.2930)	12.1109(3.2834)
(MPH)	7.9429	8.1725	7.9741	7.4405(3.2930)	8.2574(3.2834)
PORT ENGINE SHP	559.6	556.2	560.3	556.2(3.3056)	563.2(3.2709)
SHAFT RPM	152.9	153.1	152.9	151.6(3.2853)	154.8(3.2950)
STBD ENGINE SHP	551.4	548.7	549.1	548.0(3.2823)	551.4(3.2514)
SHAFT RPM	151.1	151.3	151.0	148.9(3.2938)	153.0(3.2713)
BOTH ENGINE SHP	1111.0	1104.8	1109.4	1104.8(3.3056)	1112.8(3.2647)
AVE. SHAFT RPM	152.0	152.2	152.0	150.8(3.2934)	153.3(3.2713)
STEER RUDDR(DEG,PORT+)	1.7	.1	-1.3	-13.8(3.2541)	13.0(3.2920)
FLANK RUDDR(DEG,PORT+)	1.2	1.1	1.2	1.1(3.3041)	1.2(3.2921)
DRIFT(DEG,RES+ON PORT)	-2.1792	-2.8161	-1.7655	-3.5771(3.2746)	.7304(3.2855)
YAW RATE(DEG/SECOND)	.0315	.0329	.0001	-.0843(3.2854)	.0532(3.2750)
YAW ACCEL(DEG/SEC/SEC)	-.0026	.0003	.0000	-.0061(3.2806)	.0091(3.2903)
XY ACCEL(FT/SEC/SEC)	.0181	.0209	.0277	.0007(3.2805)	.0975(3.2938)
DEPTH AT BOW(FEET)	59.8	54.1	56.4	54.1(3.3056)	60.0(3.2521)
DEPTH AT STERN(FEET)	57.8	50.5	54.9	50.5(3.3056)	57.8(3.2514)
DIST. OFF W.BANK(FEET)	584.2	902.0	785.7	584.2(3.2514)	914.8(3.3000)
E.BANK(FEET)	1771.9	2061.2	1877.3	1771.9(3.2514)	2061.2(3.3056)

IX. BACKING AND STOPPING TESTS

In addition to the turning and speed-power previously described, a number of additional tests were performed on the EXXON NASHVILLE and EXXON LAKE CHARLES to determine other characteristics of importance to both tow operating and design personnel. There were three types of tests included: 1) both tows were operated at full power astern, downstream, and then had their engines brought ahead to establish both astern power and stopping capability; 2) both tows completed two downstream maneuvers going from full ahead to full astern, then bringing the tow to an approximate stop relative to the ground, and 3) both tows completed one upstream maneuver going from full ahead to full astern bringing the tow to an approximate stop relative to the ground. Tables 9.A through 9.E in the last of this section contain summary statistics for the EXXON LAKE CHARLES astern run and the four downstream stopping tests.

9.1 Backing Tests

The first backing test performed on the EXXON NASHVILLE measured the downriver movement of the tow away from a Miniranger transponder. Both channels of the pilothouse Miniranger recorded the ranges. As a result, tow speed astern was obtained directly as the slope of a linear least square regression line fitted to the range values. When the tow was up to full power astern, speed over the ground was 14 fps or 9.5 mph. River current was 2.9 mph which gave the tow a speed of 6.6 mph through the water at about 3460 SHP and 216 RPM. The engines were then brought ahead and the tow slowed to 5 fps over the ground within a 3 minute period.

Table 9.A shows the full astern backing test and subsequent full ahead stopping test summaries for the EXXON LAKE CHARLES. The tow obtained an average speed astern of 7.6 mph over the ground (approximately 4.7 mph through the water) at 192 RPM and 2101 SHP during a 256 second run. Approximately 15 seconds later the engines were

brought ahead and the tow slowed for 211 seconds (1800 feet) to 1.1 mph over the ground (1.8 mph through the water).

9.2 Upstream Stopping Maneuvers

Two upstream crash stops were performed - - one by the EXXON NASHVILLE and one by the EXXON LAKE CHARLES. Each test was done after the completion of an upstream turn around the bend on Run 1. Figure 9.a shows the EXXON NASHVILLE's stopping maneuver in which the track of the pilothouse antenna was plotted at 30 second intervals. The description below Figure 9.a describes the sequence and shows the tow virtually stopped relative to the ground after 1½ minutes.

The EXXON LAKE CHARLES upstream stopping maneuver took place approximately 2000 feet further west and was equally effective. The tow was brought to a complete stop within 2½ minutes and approximately 1500 feet.

9.3 Downstream Crash Stops

The most important maneuver in terms of safety to towboat personnel, waterway facilities, and the environment is the ability of a tow to make emergency stops when moving downstream. Four separate tests were performed to compare the stopping performance of the EXXON NASHVILLE and EXXON LAKE CHARLES as shown in Tables 9.B through 9.E.

There are two primary ways of measuring braking performance; one, from the time the pilot first moves the throttle until the tow is stopped relative to the ground, and two, from the time the propellers start turning astern until the tow is stopped. The difference is approximately 15 seconds and 300 feet depending on tow speed. Based upon the data obtained from the tests, it takes about 30 seconds for the tow to go from full ahead RPM to full astern RPM in an emergency

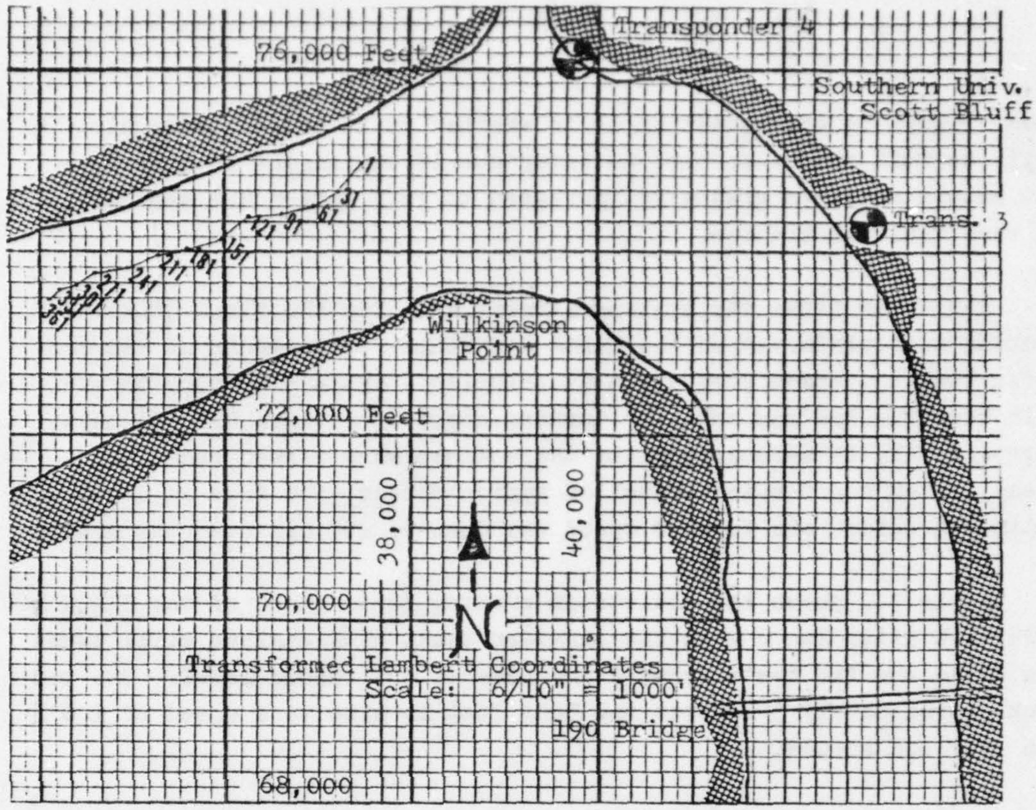

Figure 9.a EXXON NASHVILLE - Upstream Run 1
Full Ahead Stopping Test Above Bend

Notes to Figure 9.a: The position of the pilothouse antenna was plotted at 30 second intervals. At second 241, engine RPM's were reduced for astern power. At second 271, the engines were turning at about 90 percent of their rated full astern speed. Initial speed when the engines were reversed for the stopping test, tow speed was 11.88 fps (7.42 mph) over the ground. At second 361, tow speed was 2.89 fps (1.97 mph) over the ground.

mode. There is some question as to whether it is better to go directly to full astern or more advantageous if the engine is quickly put astern and then gradually increased to full astern RPM depending on the "feel" of the tow.

Table 9.B lists the braking summary data for the first downstream braking test performed on the EXXON NASHVILLE. The events at the time noted that the crash stop began at 16:05:29. Table 9.B shows that at this time the tow was actually turning about 45 reverse RPM and that approximately 15 seconds earlier the engines were slowed from full ahead. Even so, the tow travelled approximately 2500 feet in about 4 minutes before its forward speed was down to 2.4 mph over the ground.

Table 9.C shows the downstream braking performance of the EXXON NASHVILLE after Run 6 when the maneuver began with engines still turning ahead and the tow's forward progress at full ahead level. The tow took approximately 5 minutes and 3000 feet to slow to a speed of 1.6 mph over the ground.

Table 9.D and 9.E show results of the two braking tests performed by the EXXON LAKE CHARLES. The comparison between the two tests is important because the stopping test after Run 2 employed the more gradual astern RPM method described earlier. Table 9.D shows that the tow took about 7 3/4 minutes to reduce speed from 14.0 mph to 0.8 mph over the ground during which time the tow covered 4700 feet. The timing sequence for this manuever was: 1) 00:23:35, slow engines; 2) 00:23:59, engines going astern; 3) 00:24:30, engines turning about 120 astern RPM; and 4) 00:28:40, engines turning full astern at about 180 RPM. Table 9.E shows the braking maneuver completed by the EXXON LAKE CHARLES after Run 6 in which the traditional emergency stopping procedure was employed. In this case the tow was brought to a near stop in 6 minutes and 15 seconds over a distance of less than 3400 feet. The easier stopping procedure required an additional tow length to stop. Since the displacement of the EXXON NASHVILLE and EXXON

LAKE CHARLES tow was the same and the speed at the beginning of the two braking maneuvers commenced after Run 6 was nearly the same as well, the additional power of the EXXON NASHVILLE made approximately 500 feet difference in the respective stopping distances.

Figure 9.b shows the stopping performance of the Exxon tows plotted with initial speed as 1.0 and with time in minutes along the horizontal axis. The figure shows the relatively constant performance of the two tows performing an upstream crash stop and the relatively similar shape to the stopping time curves for the downstream maneuvers. Assuming a different constant for deceleration for each tow from Tables 9.B through 9.E, the distance covered during braking can be estimated from Figure 9.b using classical methods. This constant is given as the average value for "XY ACCEL (FT/SEC/SEC)".

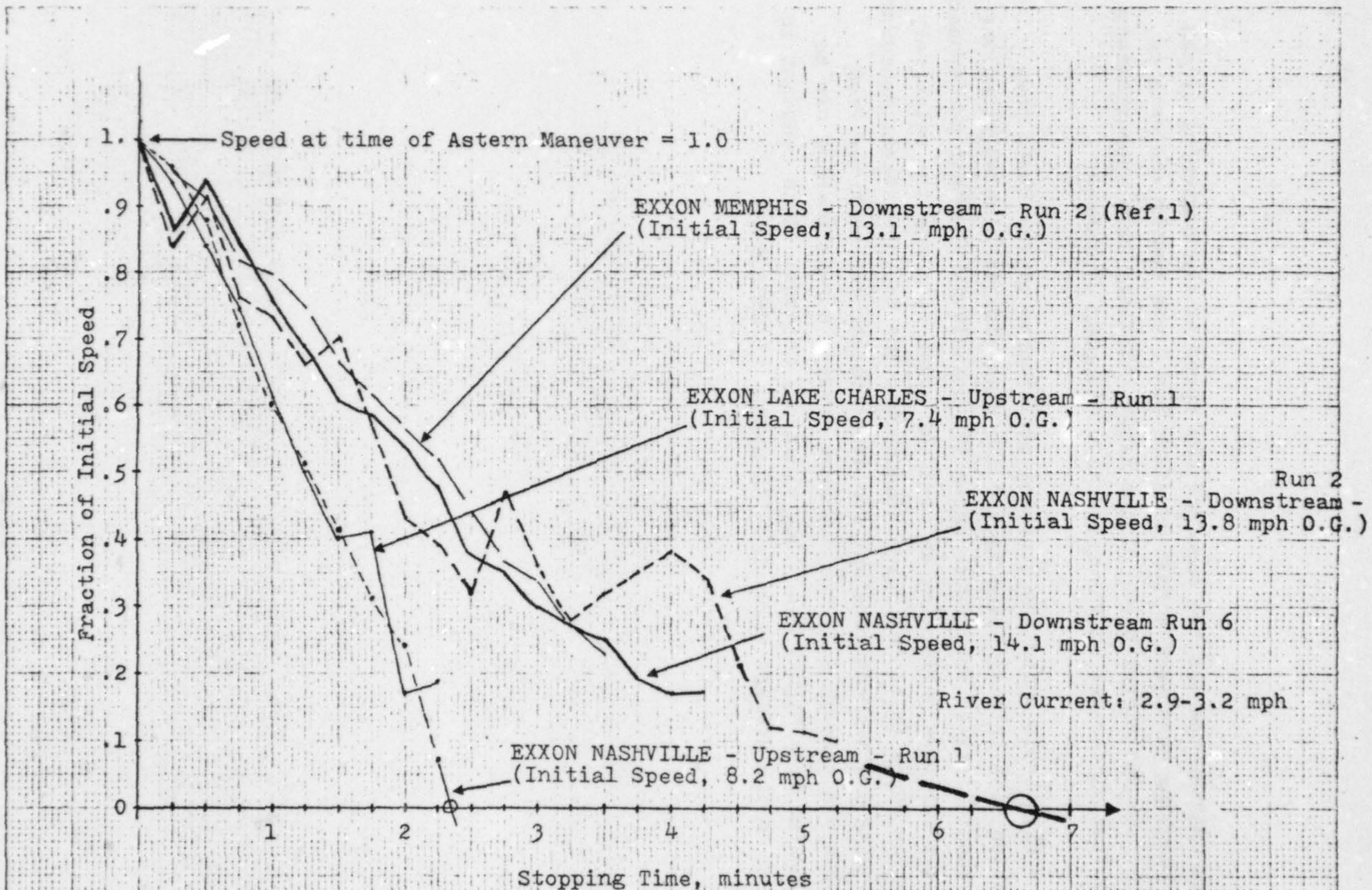

Figure 9.b Braking of Exxon Tows

Table 9.A

EXXON LAKE CHARLES - Crash Stop Executed from Full Astern to Full Ahead

** Tow Moving Full Astern **

SUMMARY TIMES(HH.MMSS) START=21.4430 END =21.4845 TOTAL SECONDS= 256

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ACTUAL DIST.
P.H. ANTENNA	53100.0	43653.4	50250.6	43597.1	2866.3
BOW ANTENNA	53999.6	43585.8	51167.6	43638.1	2857.2
CENT. GRAV.	53606.9	43615.9	50758.2	43619.8	2860.8

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY D.G.(FPS)	9.2154	11.9560	11.2164	5.8840(21.4541)	14.8679(21.4620)
(MPH)	6.2832	8.1518	7.6475	4.0118(21.4541)	10.1372(21.4620)
PORT ENGINE SHP	1075.1	939.2	1007.4	939.2(21.4845)	1075.1(21.4430)
SHAFT RPM	-188.5	-149.7	-188.1	-191.3(21.4731)	-149.7(21.4845)
STBD ENGINE SHP	1196.7	1007.0	1101.6	1007.0(21.4845)	1196.7(21.4430)
SHAFT RPM	-197.0	-145.9	-196.2	-199.9(21.4452)	-145.9(21.4845)
BOTH ENGINE SHP	2271.8	1946.2	2109.0	1946.2(21.4845)	2271.8(21.4430)
AVE. SHAFT RPM	-192.8	-147.8	-192.1	-194.9(21.4735)	-147.8(21.4845)
STEER RUDDR(DEG,PORT+)	3.1	3.3	3.2	3.0(21.4434)	3.3(21.4710)
FLANK RUDDR(DEG,PORT+)	-.3	-.7	-.5	-.7(21.4832)	-.2(21.4458)
DRIFT(DEG,RES+ON PORT)	151.7721	-178.7330	-72.4860	-179.9707(21.4731)	179.7266(21.4730)
YAW RATE(DEG/SECOND)	-.5373	.0592	.0258	-.5373(21.4430)	.2825(21.4516)
YAW ACCEL(DEG/SEC/SEC)	.0073	.0079	.0023	-.0491(21.4528)	.0616(21.4440)
XY ACCEL(FT/SEC/SEC)	.2540	.0318	.2169	.0180(21.4602)	.5594(21.4549)

** Tow Executing Crash Stop **

SUMMARY TIMES(HH.MMSS) START=21.4900 END =21.5230 TOTAL SECONDS= 211

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ACTUAL DIST.
P.H. ANTENNA	50068.1	43588.5	48641.1	43827.2	1804.7
BOW ANTENNA	50982.8	43644.3	49804.7	43545.3	1200.3
CENT. GRAV.	50575.5	43619.4	49134.0	43708.2	1724.3

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY D.G.(FPS)	12.2551	1.5722	8.2005	1.2209(21.5229)	12.2551(21.4900)
(MPH)	8.3558	1.0720	5.5912	.8324(21.5229)	8.3558(21.4900)
PORT ENGINE SHP	*	*	*	*	*
SHAFT RPM	58.7	187.0	179.7	58.7(21.4900)	193.1(21.4925)
STBD ENGINE SHP	*	*	*	*	*
SHAFT RPM	66.9	169.0	163.0	66.9(21.4900)	174.0(21.5033)
BOTH ENGINE SHP	*	*	*	*	*
AVE. SHAFT RPM	62.8	178.0	171.3	62.8(21.4900)	181.6(21.4922)
STEER RUDDR(DEG,PORT+)	3.3	3.4	3.3	3.1(21.5031)	3.4(21.5054)
FLANK RUDDR(DEG,PORT+)	-.6	-.7	-.7	-.8(21.4917)	-.5(21.5039)
DRIFT(DEG,RES+ON PORT)	-176.1358	151.5504	-98.3062	-179.9392(21.5113)	179.9667(21.4939)
YAW RATE(DEG/SECOND)	.0191	-.0973	-.0812	-.3395(21.5204)	.2474(21.5219)
YAW ACCEL(DEG/SEC/SEC)	-.0156	-.0169	-.0006	-.0549(21.5158)	.0627(21.5213)
XY ACCEL(FT/SEC/SEC)	.0576	.6345	.3844	.0099(21.4910)	2.3105(21.5212)

* No SHP Data.

Table 9.B

EXXON NASHVILLE - Downstream Run 2

Crash Stop from Full Ahead

SUMMARY TIMES(HH.MMSS) START=16.0529 END =16.0930 TOTAL SECONDS= 242

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	51627.3	42636.3	49117.9	42672.4	2509.7	2512.9
BOW ANTENNA	50579.0	42689.5	48077.5	42703.6	2501.6	2505.2
CENT. GRAV.	51111.2	42662.2	48601.1	42687.6	2510.2	2511.2

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	17.6972	3.4735	10.4205	3.4735(16.0930)	21.2278(16.0538)
(MPH)	12.0663	2.3683	7.1049	2.3683(16.0930)	14.4735(16.0538)
VELOCITY T.W.(FPS)	13.3828	1.1228	6.4855	.9659(16.0918)	16.9313(16.0538)
(MPH)	9.1246	.7656	4.4220	.6586(16.0918)	11.5440(16.0538)
PORT ENGINE SHP	1635.1	*	*	*	1678.9(16.0839)
SHAFT RPM	-31.2	-153.1	-188.[illegible]	-198.9(16.0906)	-31.2(16.0529)
STBD ENGINE SHP	1599.4	*	*	*	1599.4(16.0529)
SHAFT RPM	-58.3	-172.4	-214.7	-231.5(16.0549)	-58.3(16.0529)
BOTH ENGINE SHP	3234.5	*	*	*	3234.5(16.0529)
AVE. SHAFT RPM	-44.8	-162.7	-201.4	-213.8(16.0549)	-44.8(16.0529)
STEER RUDDR(DEG.PORT+)	10.0	.3	1.0	.3(16.0805)	12.1(16.0530)
FLANK RUDDR(DEG.PORT+)	.8	-15.2	-1.4	-16.9(16.0928)	.9(16.0539)
DRIFT(DEG.RES+ON PORT)	-.8774	-1.9058	-2.4062	-8.0690(16.0831)	.9189(16.0850)
YAW RATE(DEG/SECOND)	-.0665	.0054	-.0050	-.0876(16.0755)	.0989(16.0806)
YAW ACCEL(DEG/SEC/SEC)	.0073	.0189	.0003	-.0284(16.0812)	.0283(16.0759)
XY ACCEL(FT/SEC/SEC)	.2685	.1507	.1457	.0030(16.0606)	.8426(16.0534)
DEPTH AT BOW(FEET)	49.7	61.0	59.5	49.7(16.0529)	61.3(16.0629)
DEPTH AT STERN(FEET)	60.6	79.0	76.5	60.6(16.0529)	79.0(16.0630)
DIST. OFF W.BANK(FEET)	1044.2	929.5	945.7	929.5(16.0630)	1044.2(16.0529)
E.BANK(FEET)	1995.2	2135.0	2116.6	1995.2(16.0529)	2135.0(16.0630)

* No SHP data.

Table 9.C

EXXON NASHVILLE - Downstream Run 6

Crash Stop from Full Ahead

SUMMARY TIMES(HH.MMSS) START=12.1028 END =12.1523 TOTAL SECONDS= 296

COORDINATES(FEET):	X.START	Y.START	X.END	Y.END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52163.7	43158.0	49169.0	43775.5	3057.7	3085.1
BOW ANTENNA	51126.3	43345.1	48424.4	43650.4	2719.2	2731.4
CENT. GRAV.	51654.0	43249.2	48659.0	43689.3	3027.3	3033.2

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	20.2442	2.3080	10.2852	2.2539(12.1520)	20.7311(12.1032)
(MPH)	13.8029	1.5736	7.0126	1.5368(12.1520)	14.1349(12.1032)
VELOCITY T.W.(FPS)	15.9952	2.0402	6.2978	1.1679(12.1254)	16.4796(12.1032)
(MPH)	10.9058	1.3910	4.2939	.7963(12.1254)	11.2361(12.1032)
Port SHAFT RPM	153.2	-196.8	-181.6	-205.1(12.1431)	153.2(12.1028)
STBD SHAFT RPM	143.2	-194.8	-174.0	-199.2(12.1457)	143.2(12.1028)
AVE. SHAFT RPM	148.2	-195.8	-177.8	-201.0(12.1427)	148.2(12.1028)
STEER RUDDR(DEG,PORT+)	-3.0	-.6	-.9	-3.4(12.1029)	-.6(12.1506)
FLANK RUDDR(DEG,PORT+)	-.2	37.1	2.7	-11.9(12.1114)	41.1(12.1422)
DRIFT(DEG,RES+ON PORT)	.1668	22.1228	7.9261	-.1351(12.1236)	30.0796(12.1503)
YAW RATE(DEG/SECOND)	-.1357	.1344	-.0672	-.3022(12.1441)	.1278(12.1253)
YAW ACCEL(DEG/SEC/SEC)	.0006	.0007	.0000	-.0195(12.1417)	.0262(12.1244)
XY ACCEL(FT/SEC/SEC)	.2479	.0384	.1576	.0071(12.1203)	.4357(12.1248)
DEPTH AT BOW(FEET)	40.5	25.7	25.7	20.8(12.1344)	40.5(12.1028)
DEPTH AT STERN(FEET)	30.2	26.1	22.9	20.1(12.1314)	30.2(12.1028)
DIST. OFF W.BANK(FEET)	1652.8	1816.4	1842.5	1652.8(12.1028)	1907.3(12.1333)
E.BANK(FEET)	1352.2	1254.3	1242.3	1205.0(12.1335)	1352.2(12.1028)

Table 9.D

EXXON LAKE CHARLES - Downstream Run 2

Crash Stop from Full Ahead

SUMMARY TIMES(HH.MMSS) START= .2335 END = .3119 TOTAL SECONDS= 465

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	51655.2	42550.4	46964.5	42607.8	4691.2	4740.1
BOW ANTENNA	50648.8	42559.9	45945.2	42616.1	4704.0	4714.5
CENT. GRAV.	51147.1	42555.2	46456.3	42611.9	4691.2	4711.1

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	20.5738	.8424	10.1542	.8424(.3119)	20.5738(.2335)
(MPH)	14.0276	.5743	6.9233	.5743(.3119)	14.0276(.2335)
VELOCITY T.W.(FPS)	16.2722	3.6325	6.8344	.1939(.2945)	16.2722(.2335)
(MPH)	11.0947	2.4767	4.6598	.1322(.2945)	11.0947(.2335)
Port SHAFT RPM	198.0	-164.6	-141.4	-179.2(.2950)	198.0(.2335)
STBD SHAFT RPM	- 193.3	-188.3	-143.1	-188.3(.3119)	193.3(.2335)
AVE. SHAFT RPM	195.7	-176.5	-142.3	-182.4(.2947)	195.7(.2335)
STEER RUDDR(DEG,PORT+)	-3.4	.7	.0	-4.4(.2352)	1.2(.2726)
FLANK RUDDR(DEG,PORT+)	1.8	1.0	1.4	.9(.3004)	2.4(.2353)
DRIFT(DEG,RES+DN PORT)	-.0445	37.8272	1.3536	-60.9553(.2858)	38.4636(.3117)
YAW RATE(DEG/SECOND)	.0277	.0802	-.0000	-.2335(.2914)	.2388(.2857)
YAW ACCEL(DEG/SEC/SEC)	-.0021	.0055	.0001	-.0510(.2906)	.0251(.2853)
XY ACCEL(FT/SEC/SEC)	.0627	.0719	.0972	.0022(.2538)	1.1143(.2906)
DEPTH AT BOW(FEET)	54.1	60.0	58.3	54.1(.2335)	60.1(.3037)
DEPTH AT STERN(FEET)	55.6	60.1	59.3	55.6(.2335)	60.6(.2924)
DIST. OFF W.BANK(FEET)	932.0	696.5	749.8	681.4(.2947)	932.0(.2335)
E.BANK(FEET)	2086.6	2282.7	2243.8	2086.6(.2335)	2294.8(.2945)

Table 9.E

EXXON LAKE CHARLES - Downstream Run 6

Crash Stop from Full Ahead

SUMMARY TIMES(HH.MMSS) START= 6.0447 END = 6.1111 TOTAL SECONDS= 385

COORDINATES(FEET):	X,START	Y,START	X,END	Y,END	ST.LINE DIST.	ACTUAL DIST.
P.H. ANTENNA	52880.9	42628.7	49543.4	42604.8	3337.6	3345.4
BOW ANTENNA	51851.8	42648.6	48518.9	42669.8	3333.2	3337.7
CENT. GRAV.	52372.7	42638.4	49036.2	42637.0	3336.5	3338.3

PERFORMANCE STATISTICS:	START	END	AVERAGE	MINIMUM(HH.MMSS)	MAXIMUM(HH.MMSS)
VELOCITY O.G.(FPS)	19.1847	.5360	8.6966	.5360(6.1111)	19.2251(6.0452)
(MPH)	13.0804	.3654	5.9295	.3654(6.1111)	13.1080(6.0452)
VELOCITY T.W.(FPS)	14.8566	3.8128	5.5862	.4796(6.1023)	14.9055(6.0452)
(MPH)	10.1295	2.5997	3.8088	.3270(6.1023)	10.1628(6.0452)
Port SHAFT RPM	170.0	-153.9	-161.2	-181.8(6.0529)	170.0(6.0447)
STBD SHAFT RPM	171.3	-163.2	-160.9	-188.2(6.1101)	171.3(6.0447)
AVE. SHAFT RPM	170.6	-158.5	-161.1	-183.9(6.1101)	170.6(6.0447)
STEER RUDDR(DEG,PORT+)	-5.6	.6	.0	-5.9(6.0508)	1.4(6.0527)
FLANK RUDDR(DEG,PORT+)	.3	.5	.5	-4.6(6.0805)	1.4(6.0513)
DRIFT(DEG.RES+ON PORT)	-1.3511	-12.4509	-2.2430	-14.2287(6.1008)	4.1215(6.1028)
YAW RATE(DEG/SECOND)	-.0074	.0308	.0065	-.0509(6.0715)	.0596(6.1049)
YAW ACCEL(DEG/SEC/SEC)	-.0017	-.0025	.0000	-.0063(6.0859)	.0075(6.0913)
XY ACCEL(FT/SEC/SEC)	.0398	.0185	.0884	.0050(6.0535)	.3121(6.1016)
DEPTH AT BOW(FEET)	45.2	57.5	56.0	45.2(6.0447)	59.7(6.0922)
DEPTH AT STERN(FEET)	51.1	58.5	60.0	51.1(6.0447)	63.0(6.0844)
DIST. OFF W.BANK(FEET)	1075.5	976.9	975.5	942.0(6.0901)	1075.5(6.0447)
E.BANK(FEET)	1877.6	2099.5	2100.6	1877.6(6.0447)	2175.3(6.0902)

X. DATA PROCESSING ACTIVITIES

This section of the report describes the computer processing and related activities required to transform the tow test data collected during the Exxon trials into logical records for evaluating tow and waterway interactions. The methodology employed by RMSA was to develop a list of tow performance parameters which would be measured or calculated during the Exxon tow trials, field survey, or data reduction tasks of the study. This list of performance variables, given in Table 10.A, was based on the test data developed during the November 1976 Exxon trials [1].

The majority of performance data was generated from the Miniranger ranges obtained as described in Section 4.4. Of the 42 variables shown in Table 10.A, 24 of them were obtained directly from the Miniranger data. The range data were also the only data kept as originally recorded (except for editing) as part of the final computer files on tow trial performance. Rudder angle voltages obtained by RMSA as described in Section 4.1 were converted to degrees for inclusion in the data base. Shaft revolution voltages were adjusted to reflect voltage to RPM ratios different from that specified by the manufacturer. Current, depth, and distance off data were included by combining published survey data with the data obtained by RMSA during the current measurement activity described in Section 3.3.

Prior to the data reduction activity, the times recorded by RMSA and Exxon were compared and discrepancies rationalized. Of major concern was the time relation between the SHP measurements and the Datalogger shaft tachometer voltage recordings so that the more accurate measurements could be used to normalize RMSA's more frequent recording of shaft tachometer voltage.

Key event times such as the time when abeam the straight course range markers, were independently recorded by the participants and of considerable use after the tests in correcting for the different clock error rates of the two Miniranger units and Datalogger.

The remaining sections describe the specific activities required to provide values for the 42 performance variables given in Table 10.A. In order to put the magnitude of this activity in perspective, Tables 10.B and 10.C list the data files developed from the two Exxon tow tests. The EXXON NASHVILLE tests shown in Table 10.B spanned 2 days, covered over a dozen types of tests, and resulted in 19 data files with over $4\frac{1}{2}$ hours of dynamic parameter data. The EXXON LAKE CHARLES because of its slower speed, made fewer test runs but generated over 900 more seconds of data.

10.1 Range Measurement Data Processing

The most critical portion of the data processing activities related to the reduction of the range data recorded during the trials into smoothed X, Y coordinates. To accomplish this, the processing sequence shown in Figure 10.a was employed using computer algorithms to perform the necessary computations. This section discusses the statistical and analytical considerations employed to transform the raw range data into a second-by-second mapping of tow positions and attitudes. Examples of the resulting computerized data are given in Appendix F which contains a listing of the 42 variables generated during Run 1, Part 2 (Table 10.B) of the EXXON NASHVILLE trials. The listing is given at 30 second intervals so as to fit on four pages.

Figure 10.a shows two large blocks on the left indicative of the effort required to provide an ordered array of range data indexed according to the time and test number of each trial run. The first block portrays the manual editing procedures taken to prepare the recorded range measurements for data entry and computer storage prior to analysis. The second block indicates the on-line editing procedures required to check the computer data, correct errors, and monitor processing activities.

A series of twelve numbered blocks follow which describe the algorithmic sequence of the calculations. The critical nature of this processing sequence is demonstrated by the fact that four range measurements from the trials generated numeric values for 12 dynamic parameters which describe tow motions. Figure 10.b lists and describes the parameters computed from the initial range measurements together with the associated Table 10.A variable number.

The range processing sequence and underlying rationale was patterned after the methodology used to process data in the first Exxon test [1]. Generally, the data were manually edited to discard obviously bad range values. The valid data were then entered into the computer and then smoothed using a linear least-square regressions. The initial smoothing usually resulted in a standard error for the sample of between 1 and 2 meters. After the X, Y antenna coordinates were calculated, the linear smoothing regression usually resulted in standard errors between 1 and 2 feet. Subsequent linear regressions fitted the X, Y values against time with the first differential generating coordinate velocity. The slope of the linear regression line fitted to the coordinate velocity became tow acceleration. As a result of using this technique, the velocity and acceleration data are instantaneous values and can be used later as part of integral expressions to describe tow behavior.

10.2 Horsepower, Rudder, and RPM Data Processing

The horsepower data were tabulated at about 1 minute intervals and provided after the tests. These SHP values were inserted into the data base at the corresponding second of time based upon the measurement technique used during the trials (See Section 4.3). The RPM values furnished to RMSA were used to normalize the Datalogger voltages recorded. That is, the first RPM value measured during a given test run segment was used by RMSA to calibrate the average voltage recorded during the

ensuing minute - usually 16 values for each shaft. The actual voltages recorded during the trials for RPM were entered into the data base. These values were then adjusted by multiplying by the RPM/voltage calibration fraction.

The rudder angle voltages were similarly entered into the program as voltages and then became the independent variable for the equations given in Table 4.A, page 36. A nominal smoothing linear regression equation was used to fit 3 points and calculate intermediate values.

Tested SHP values which were entered into the data base were fitted to three points and used to compute intermediate SHP values. Where the data base extended outside of the test measurements, a limited amount of extrapolation was done. However, where extrapolation did not fit the known test circumstances, the SHP variable was left at zero.

10.3 Current, Depth, and Distance Off Calculations

The waterway profiles and current tests described in Section 3.3 form the basis for current, depth, and distance off bank values entered into the data base. The X,Y coordinates for the bow and pilothouse antennas were used to place the tow at one of the river cross-sections (A through N) from which the depth at that point, distance to each bank, and current velocity were measured. These values were then interpolated between cross-sections by fitting 3 points to a polynomial and calculating intermediate values as a function of time. Where too few cross-section data could be developed, constants were entered.

It should be noted that although this method only approximates depth, width and current effects along a tow's path, the Baton Rouge area would be difficult to model more definitively because of the numerous structures and contour irregularities.

Table 10.A

Tow Performance Variables

Variable Number	Variable Description
1	Pilothouse antenna range, Miniranger channel A, meters
2	" " " , " channel B, "
3	Bow antenna range, Miniranger channel A, meters
4	" " " , " channel B, "
5	Adjusted pilothouse range, channel A, meters
6	" " " , channel B, meters
7	" bow range, channel A, meters
8	" " " , channel B, meters
9	Geographic X position of pilothouse antenna, feet*
10	" Y " " " " , feet*
11	Geographic X position of bow antenna, feet*
12	" Y " " " " , feet*
13	Geographic X position of tow center of gravity, feet*
14	" Y " " " " " " , feet*
15	Tow heading, ψ , degrees*
16	Tow velocity at center of gravity, X direction, $\dot{X}$, feet/second
17	Tow velocity at center of gravity, Y direction, $\dot{Y}$, feet/second
18	Resultant velocity at center of gravity, U, $U^2=\dot{X}^2+\dot{Y}^2$, feet/second
19	Yaw rate, $\dot{\psi}$, degrees/second*
20	Drift angle, β , $\sin^{-1}(-\dot{X}/U)$, degrees
21	Tow acceleration at center of gravity, X direction, $\ddot{X}$, feet/second/second
22	Tow acceleration at center of gravity, Y direction, $\ddot{Y}$, feet/second/second
23	Resultant acceleration at center of gravity, $\ddot{X}^2+\ddot{Y}^2$, feet/second/second
24	Yaw acceleration, $\ddot{\psi}$, degrees/second/second
25	Steering rudder angle, δ_s , degrees, positive to port
26	Flanking rudder angle, δ_f , degrees, positive to port

Table 10.A (continued)

27	Port engine shaft horsepower, SHP
28	Port shaft revolutions per minute, RPM**
29	Starboard engine shaft horsepower, SHP
30	Starboard shaft revolutions per minute, RPM**
31	Total shaft horsepower, SHP
32	Average shaft revolutions per minute, RPM**
33	Current velocity at stern, X direction, $\dot{X}_C$, feet/second
34	" " " " , Y " , $\dot{Y}_C$, " / "
35	" " " bow, X direction, $\dot{X}_C$, feet/second
36	" " " " , Y " , $\dot{Y}_C$, " / "
37	Depth of water at stern, feet
38	" " " " bow, feet
39	Pilothouse antenna distance off west or south bank, feet
40	" " " " east or north " , "
41	Bow antenna distance off west or south bank, feet
42	" " " " east or north bank, "

* Based upon a Lambert Plane Coordinate grid, Lambert grid positive Y, assumed as true north. Variables are transormed with X being positive north. (Lambert Y minus 6x10^5 feet) and Y being positive north. (Lambert minus 2 x 10^6 feet). The Z axis (depth) positive down. Rotation positive clockwise about Z axis.

** Shaft revolutions per minute, RPM, are positive ahead and negative astern.

Table 10.B

EXXON NASHVILLE Data File Structure

Run	Part	Test Data File Description	Clock Time Begin	Clock Time End	Total Seconds
1	1	Upriver, Full Power, Approach Straight-Course	14:17:00	14:27:59	660
1	2	" , " " , Straight-Course	14:27:00	14:46:59	1200
1	3	" , ½ Power, Turn in Bend	14:46:30	15:05:29	1140
1	4	" , Full Power, Crash Stop	15:05:00	15:11:29	390
2	1	Downriver, ½ Power, Turn in Bend	15:37:00	15:52:59	960
2	2	" , Full Power, Straight-Course, Crash Stop	15:52:00	16:09:59	1080
3	1	Upriver, 3/4 Power, Approach Straight-Course	17:01:00	17:12:29	690
3	2	" , " " , Straight-Course	17:12:00	17:31:59	1200
3	3	" , ½ Power, Turn in Bend	17:31:30	17:51:29	1200
3	4	" , Various Powers, Maneuvers in Bend	17:51:00	18:00:59	600
4	1	Downriver, ½ Power, Turn in Bend	18:51:00	19:10:59	1200
4	2	" , " " , Straight-Course	19:10:30	19:25:29	900
A	-	Downriver, Full Power Astern (No Bow or Datalogger Data)	09:28:00	09:33:59	360
5	1	Upriver, Full Power, Approach to Zig-Zag	10:06:00	10:16:59	660
5	2	" , " " , Zig-Zag Run	10:16:30	10:36:29	1200
5	3	" , ½ Power, Turn in Bend	10:36:00	10:54:59	1140
5	4	" , " " , Maneuvers in Bend	10:54:30	10:59:59	330
6	1	Downriver, ½ Power, Turn in Bend	11:42:00	11:56:59	900
6	2	" , Full Power, Zig-Zag, Crash Stop	11:56:00	12:15:59	1200
			Total Seconds of Data		17,010

Table 10.C

EXXON LAKE CHARLES Data File Structure

Run	Part	Test Data File Description	Clock Time Begin	Clock Time End	Total Seconds
A		Downriver, Full Power, Astern, Stop	21:44:00	21:52:59	540
1	1	Upriver, Full Power, Approach, Straight-Course	22:19:00	22:32:29	810
1	2	" , " " , Straight-Course	22:32:00	22:51:59	1200
1	3	" , Slow to ½ Power, Approach Bend	22:51:30	22:59:29	480
1	4	" , ½ Power, Turn in Bend	22:59:00	23:18:59	1200
1	5	" , Full Power, Crash Stop	23:18:30	23:31:29	780
2	1	Downriver, ½ Power, Turn in Bend	23:53:00	24:12:59	1200
2	2	" , Full Power Straight-Course, Crash Stop	00:12:30	00:31:29	1140
3	1	Upriver, 3/4 Power, Approach Straight-Course	01:27:00	01:35:59	540
3	2	" , " " , Straight-Course	01:35:00	01:54:59	1200
3	3	" , Slow to ½ Power, Approach Bend	01:54:30	02:03:29	540
3	4	" , 3/4 Power, Turn in Bend	02:03:00	02:22:29	1170
4	1	Downriver, 3/4 Power, Turn in Bend	03:01:00	03:19:59	1140
4	2	" , ½ Power, Straight-Course	03:19:30	03:39:29	1200
4	3	" , Various Powers and Maneuvers	03:39:00	03:47:29	510
5	1	Upriver, Full Power, Approach Zig-Zag	04:38:30	04:51:29	780
5	2	" , " " , Zig-Zag	04:50:30	05:10:29	1200
6	1	Downriver, Various Powers, Approach Zig-Zag	05:36:00	05:54:59	1140
6	2	" , Full Power, Zig-Zag, Crash Stop	05:54:00	06:11:59	1200
			Total Seconds of Data		17,970

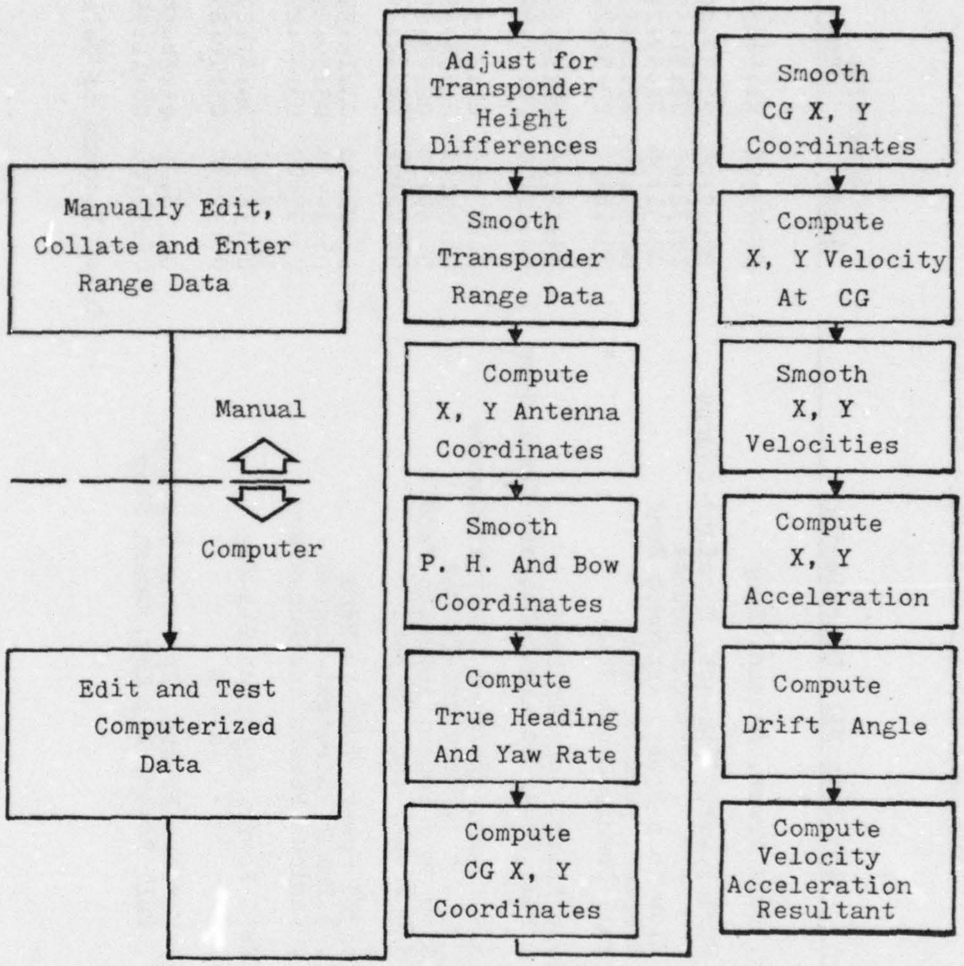

Figure 10.a Range Measurement Processing Sequence

Input	Table 10.A Variable Number		Output	Table 10.A Variable Number
• t		Range Measurement Computer Processing	• $\hat{R}_1, \hat{R}_2, \hat{R}_3, \hat{R}_4$	5, 6, 7, 8
• R_1	1	(See Figure 10.a)	• X_P, Y_P, X_B, Y_B	9,10,11,12
• R_2	2		• $\psi, \dot{\psi}, \ddot{\psi}$	15,19,24
• R_3	3		• $X_G, \dot{X}_G, \ddot{X}_G$	13,16,21
• R_4	4		• $Y_G, \dot{Y}_G, \ddot{Y}_G$	14,17,22
			• $\beta, U, \dot{U}$	20,18,23

Description

t = time(seconds)

R = Range(meters) between antenna and transponder

X = Geographic north-south axis, positive northward(feet)

Y = " east-west axis, positive eastward(feet)

$\dot{X} = dX/dt$ = velocity(feet/second)

$\dot{Y} = dY/dt$ = " (")

$\ddot{X} = d^2X/dt^2$ = acceleration(feet/second^2)

$\ddot{Y} = d^2Y/dt^2$ = " (")

ψ = true heading angle of the tow(degrees)

$\dot{\psi} = d\psi/dt$ = yaw rate(degrees/second)

$\ddot{\psi} = d^2\psi/dt^2$ = angular acceleration(degrees/second^2)

$U = (\dot{X}^2 + \dot{Y}^2)^{\frac{1}{2}}$ = resultant velocity(feet/second)

$\dot{U} = (\ddot{X}^2 + \ddot{Y}^2)^{\frac{1}{2}}$ = " acceleration(feet/second^2)

β = drift angle(degrees) measured from U to the tow's heading, positive clockwise

Notation

B, subscript denoting bow antenna
P, " " pilothouse antenna
G, " " center of gravity
^, denotes revised or smoothed value

Figure 10.b Computed Tow Parameters

REFERENCES

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[3] U.S. Department of Commerce, Coast and Geodetic Survey, "Plane Coordinate Projection Tables, Louisiana (Lambert)", Special Publication No. 291, GPO, Washington 1962.

[4] Breed, C.B. and Hosmer, G.L., <u>Higher Surveying</u>, Vol. II, Revised by Bone, A.J., Eighth Edition, John Wiley & Sons, Inc., New York.

[5] Corps of Engineers, "Flood Control and Navigation Maps of the the Mississippi River, Cairo, Illinois to the Gulf of Mexico", 42nd Ed., Vicksburg, Miss., 1974.

[6] John Fluke Mfg. Co., Inc., "Data Logger", Mountlake Terrace, WA. Describes the characteristics of the Fluke 2240A and 2240B Dataloggers.

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APPENDIX A

EXXON NASHVILLE TEST SEQUENCE

RUN 1 (11-8-77) UPSTREAM - FULL POWER STRAIGHT COURSE - HALF POWER TURN - CRASH STOP

14:27:18	Pilothouse abeam South Range mark.
14:34:26	" " Mid " "
14:41:12	" " North " "
- -	Reduced speed for half power turn.
14:48:47	Pilothouse abeam 190 Bridge.
14:52:13	Pilot placed rudder 15° to port.
15:00:15	Pilot began steering as current caught bow of tow. Began to accelerate for full power upstream stop.
15:07:53	Preparing for crash astern.
15:09:01	Began crash astern.
15:11:31	Tow apparently dead in water.

RUN 2 (11-8-77) DOWNSTREAM - HALF POWER TURN - FULL POWER STRAIGHT COURSE - CRASH STOP

15:36:41	Began downstream run around bend with engines at 590 RPM. Various rudder angles used.
15:45:38	Turn completed. Began accelerating for full power run.
15:52:28	Pilothouse abeam 190 Bridge.
15:55:48	" " North Range mark.
16:00:05	" " Mid " "
16:04:32	" " South " "
16:05:29	Began crash stop.
16:09:30	Tow apparently dead in water.

RUN 3 (11-8-77) UPSTREAM - 3/4 POWER STRAIGHT COURSE - HALF POWER TURN

16:59:56	Started recording trial run data.
17:12:12	Pilothouse abeam South Range mark.
17:20:13	" " Mid " "
17:27:41	" " North " "
17:36:24	" " 190 Bridge.
17:38:28	Pilot put rudder 15° to port.
17:44:28	Pilot stopped turn maneuver due to traffic in bend. Various rudder and engine maneuvers used as the tow was maneuvered clear of second tow downbound in the channel.

EXXON NASHVILLE TEST SEQUENCE (cont.)

RUN 4 (11-8-77) DOWNSTREAM - CONTINUOUS HALF POWER RUN - AROUND BEND - STRAIGHT COURSE

18:50:17	Began downstream run with 555 RPM on starboard and 580 RPM on port engine. Various rudder angles used around bend.
19:13:27	Pilothouse abeam North Range mark.
19:18:46	" " Mid " "
19:24:16	" " South " "
- -	Tests secured after completing course due to rain.

RUN A (11-9-77) DOWNSTREAM - FULL POWER ASTERN - CRASH STOP

09:28:05	Began recording tow position with pilothouse miniranger unit. Engines and tow moving full astern.
09:31:23	Began crash stop.
09:31:53	Engines put ahead.
09:33:17	Tow apparently dead in water.
- -	A steady speed, full power astern run was made at the start of the tests to determine the power developed astern. Only the pilothouse miniranger unit was employed to track the tow. After the tow had reached a steady astern speed, the engines were brought ahead to see how rapidly the tow could be brought dead in the water.

RUN 5 (11-9-77) UPSTREAM - FULL POWER ZIG-ZAG - HALF POWER TURN

10:05:46	Began accelerating for upstream zig-zag test.
10:16:49	Pilothouse abeam South Range mark - 10° to starboard.
10:17:55	10° left heading achieved - rudder put 10° to starboard.
10:20:56	10° right " " - " " " " port.
10:23:46	10° left " " - " " " " starboard.
10:25:03	Pilothouse abeam Mid Range mark.
10:26:43	10° right heading achieved - 10° left rudder used to bring tow to original course.
10:32:30	Pilothouse abeam North Range mark.
- -	Speed reduced for half power for turn.
10:41:17	Pilothouse abeam 190 Bridge.
10:43:30	Pilot put rudder 15° to port.
- -	About 55° of the turn were completed before the tow was out of shape and rudder and engine maneuvers were required.
10:59:08	Test run ended.

EXXON NASHVILLE TEST SEQUENCE (cont.)

RUN 6 (11-9-77) DOWNSTREAM - HALF POWER TURN - FULL POWER ZIG-ZAG - CRASH STOP

11:41:56	Began half power downstream turn using approximately 565 RPM and variable rudder.
11:51:24	RPM increased as tow cleared bend.
11:55:49	Pilothouse abeam 190 Bridge.
12:00:41	Pilothouse abeam North Range mark - rudder put 10° to port.
12:02:30	Not quite 10° left heading achieved as traffic on port side required course change. Rudder put 10° to starboard.
12:05:03	10° right heading achieved - rudder put 10° to port.
12:05:09	Pilothouse abeam Mid Pange mark.
12:08:16	10° left heading achieved - rudder put 10° to starboard.
12:09:52	Pilothouse abeam South Range mark.
12:10:28	Began crash stop.
12:15:23	Tow apparently dead in water - EXXON NASHVILLE tests completed.

APPENDIX B

EXXON LAKE CHARLES TEST SEQUENCE

RUN A (11-10-77) DOWNSTREAM - FULL POWER ASTERN - CRASH STOP

21:43:42	Beginning astern run.
21:48:45	Engines put ahead.
21:52:20	Tow apparently dead in water - test stopped.

RUN 1 (11-10-77) UPSTREAM - FULL POWER STRAIGHT COURSE - HALF POWER TURN - CRASH STOP

22:19:12	Began accelerating for upstream run.
22:32:09	Pilothouse abeam South Range mark.
22:40:32	" " Mid " "
22:48:15	" " North " "
- -	Slowed for half power turn.
22:58:59	Pilothouse abeam 190 Bridge.
23:03:30	Began steady turn using 15° port rudder.
23:18:26	Over 90° of left turn completed. Tow began to accelerate to full ahead for crash stop.
23:28:21	Began crash stop.
23:31:11	Tow apparently dead in water.

RUN 2 (11-10-77) DOWNSTREAM - HALF POWER TURN - FULL POWER STRAIGHT COURSE - CRASH STOP

23:57:40	Half power turn underway using variable rudder and constant throttle.
00:07:42	Pilothouse abeam 190 Bridge. Began accelerating for full power run.
00:13:19	Pilothouse abeam North Range mark.
00:17:46	" " Mid " "
00:22:34	" " South " "
00:23:43	Began crash stop.
00:31:19	Tow apparently dead in water - test stopped.

RUN 3 (11-11-77) UPSTREAM - CONTINUOUS 3/4 POWER STRAIGHT COURSE AND TURN

01:28:00	Began recording data.
01:35:57	Pilothouse abeam South Range mark.
01:45:41	" " Mid " "
01:54:37	" " North " "
02:05:05	" " 190 Bridge.
02:09:26	Pilot put rudder 15° to port - constant throttle.
02:20:50	Began rudder movements - constant throttle.
02:22:00	Turn ended.

EXXON LAKE CHARLES TEST SEQUENCE (cont.)

<u>RUN 4 (11-11-77)</u> DOWNSTREAM - 3/4 POWER TURN - HALF POWER STRAIGHT COURSE

03:00:00	Began downstream turn at 3/4 power using 665 RPM on port and 648 RPM on starboard engine.
03:04:30	Tow in turn using 10° to 20° right rudder and constant throttle.
03:13:33	Pilothouse abeam 190 Bridge. Power reduced to half throttle (580 RPM port, 585 RPM starboard).
03:19:36	Pilothouse abeam North Range mark.
03:25:14	" " Mid " "
03:30:56	" " South " "
- -	Tow data recorded until pusher joined bow of tow well south of I-10 Bridge.

<u>RUN 5 (11-11-77)</u> UPSTREAM - FULL POWER ZIG-ZAG

04:38:19	Began upstream run.
04:51:02	Pilothouse abeam South Range mark. Rudder put 10° to port.
04:52:21	10° left heading achieved - rudder put 10° to starboard.
04:55:10	" right " " - " " " " port.
04:58:03	" left " " - " " " " starboard.
05:00:18	Pilothouse abeam Mid Range mark.
05:00:46	10° right heading achieved - rudder put 10° to port.
05:03:44	" left " " - " " " " starboard.
05:06:22	" right " " - " " " " port.
05:09:08	Pilothouse abeam North Range mark.
- -	Test completed and tow turned south of 190 Bridge.

<u>RUN 6 (11-11-77)</u> DOWNSTREAM - FULL POWER ZIG-ZAG - CRASH STOP

- -	Tow backed upriver to allow for acceleration into full power downstream zig-zag run. Data recorded during backing and acceleration.
05:54:54	Pilothouse abeam North Range mark - rudder put 10° to port.
05:56:31	10° left heading achieved - rudder put 10° to starboard.
05:59:17	" right " " - zig-zag test abandoned due to anchored vessels in path of tow. Tow straightened on course and test continued as full power straight course run.
06:04:47	Pilothouse abeam South Range mark.
06:04:55	Began crash astern.
06:11:11	Tow apparently dead in the water. EXXON LAKE CHARLES tests completed.

APPENDIX C

EXXON NASHVILLE SHAFT HORSEPOWER MEASUREMENTS

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-8-77	1	14:17:41	213.15	1715.38	211.05	1642.74	212.10	3358.12
"	1	14:18:58	214.00	1712.79	208.70	1616.81	211.35	3329.59
"	1	14:20:10	213.57	1715.93	206.47	1592.40	210.02	3308.33
"	1	14:21:44	213.00	1720.02	207.33	1594.75	210.17	3314.77
"	1	14:22:58	213.00	1704.39	208.00	1596.56	210.50	3300.95
"	1	14:24:04	213.00	1690.26	208.00	1596.59	210.50	3286.85
"	1	14:25:20	213.00	1699.03	208.00	1596.63	210.50	3295.66
"	1	14:27:18	213.00	1712.54	208.31	1599.12	210.65	3311.66
"	1	14:27:23	213.00	1713.12	208.32	1599.23	210.66	3312.34
"	1	14:28:36	213.00	1708.68	208.51	1600.79	210.75	3309.46
"	1	14:29:30	213.00	1705.47	208.72	1605.53	210.86	3311.00
"	1	14:30:44	213.00	1709.10	209.01	1612.16	211.00	3321.27
"	1	14:31:57	213.00	1712.68	209.01	1612.20	211.00	3324.88
"	1	14:33:11	213.00	1712.67	209.01	1612.24	211.00	3324.91
"	1	14:34:13	213.00	1712.66	209.24	1617.53	211.12	3330.20
"	1	14:34:26	212.88	1711.69	209.30	1618.82	211.09	3330.51
"	1	14:35:28	212.43	1707.86	209.52	1623.88	210.98	3331.73
"	1	14:36:24	212.00	1704.22	209.74	1622.33	210.87	3326.55
"	1	14:37:39	212.00	1700.20	210.03	1620.24	211.01	3320.44
"	1	14:38:40	212.00	1696.99	210.48	1623.74	211.24	3320.73
"	1	14:39:56	212.00	1700.40	211.05	1628.18	211.52	3328.58
"	1	14:41:12	212.00	1703.99	210.49	1628.11	211.24	3332.10
"	1	14:41:20	212.00	1704.17	210.46	1628.11	211.23	3332.28
"	1	14:42:22			210.03	1628.04		
"	1	14:48:49	166.00	784.67				
"	1	14:49:58	165.62	785.11	146.91	502.66	156.27	1287.78
"	1	14:51:54	165.00	785.83	146.30	510.44	155.65	1296.27
"	1	14:53:04	165.00	782.49	146.46	517.00	155.73	1299.49
"	1	14:53:58	165.00	779.91	146.68	529.51	155.84	1309.42
"	1	14:55:08	164.47	798.65	146.97	545.43	155.72	1344.07
"	1	14:56:10	164.00	815.39	146.97	557.93	155.48	1373.32
"	1	14:57:19	164.56	843.78	146.97	571.85	155.77	1415.62
"	1	14:58:14	165.00	866.11	147.39	566.95	156.20	1433.06
"	1	14:59:31			147.99	559.89		
"	1	15:09:00	START AHEAD CRASH STOP					
"	1	15:09:31	CLUTCH CHANGE FROM AHEAD TO ASTERN MODE COMPLETED					
"	1	15:09:34	200.00	1708.96				
"	1	15:10:44			192.33	1507.26		
11-8-77	2	15:37:14	160.00	861.06				
"	2	15:38:21	160.00	840.97	134.77	505.26	147.38	1346.23
"	2	15:39:22	160.00	822.39	135.01	471.02	147.51	1293.42
"	2	15:40:28	160.00	816.82	135.27	434.44	147.63	1251.26
"	2	15:41:30	160.00	811.50	135.27	429.64	147.63	1241.14
"	2	15:42:35	160.00	797.13	135.27	424.62	147.63	1221.75

EXXON NASHVILLE SHAFT HORSEPOWER MEASUREMENTS (CONT.)

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-8-77	2	15:43:38	160.00	783.42	135.27	433.65	147.63	1217.07
"	2	15:44 51			135.27	444.29		
"	2	15:55:50	211.00	1732.87				
"	2	15:57:00	211.50	1725.75	206.98	1583.87	209.24	3309.61
"	2	15:58:10	212.00	1718.67	207.49	1591.59	209.74	3310.26
"	2	15:59:19	212.51	1722.83	208.00	1599.32	210.26	3322.16
"	2	16:00:05	212.87	1725.67	208.00	1599.35	210.43	3325.02
"	2	16:00:25	213.00	1726.76	208.00	1599.36	210.50	3326.11
"	2	16:01:34	213.00	1722.73	208.00	1599.39	210.50	3322.12
"	2	16:02:37	213.00	1719.11	208.96	1606.81	210.98	3325.92
"	2	16:03:46	213.00	1723.03	210.03	1615.07	211.51	3338.09
"	2	16:04:32	213.00	1725.80				
"	2	16:04:52	213.00	1726.72				
"	2	16:05:29	START CRASH STOP					
"	2	16:05:59	CLUTCH CHANGE FROM AHEAD TO ASTERN MODE COMPLETED					
"	2	16:06:35	195.00	1570.35				
"	2	16:07:36	197.09	1622.89	193.25	1533.73	195.17	3156.62
"	2	16:08:31	199.00	1671.67				
"	2	16:09:30	NEAR END OF CRASH STOP					
11-8-77	3	17:00:21	198.00	1402.33				
"	3	17:01:31	198.00	1388.36	190.71	1213.75	194.35	2602.11
"	3	17:02:40	198.00	1374.59	190.47	1218.75	194.23	2593.34
"	3	17:03:57	198.00	1374.54	190.20	1224.23	194.10	2598.77
"	3	17:05:03	198.00	1374.49	190.20	1223.11	194.10	2597.61
"	3	17:10:55	198.00	1374.26	190.20	1217.16	194.10	2591.42
"	3	17:12:12	198.00	1374.20	190.20	1210.46	194.10	2584.66
"	3	17:12:15	198.00	1374.20	190.20	1210.19	194.10	2584.39
"	3	17:13:36	198.00	1365.14	190.20	1203.14	194.10	2568.27
"	3	17:14:17	198.00	1360.66	190.20	1198.50	194.10	2559.16
"	3	17:15:35	198.00	1372.75	190.20	1189.29	194.10	2562.04
"	3	17:16:29	198.00	1381.12	190.63	1189.05	194.31	2570.18
"	3	17:17:45	198.00	1384.58	191.22	1188.71	194.61	2573.28
"	3	17:18:54	198.00	1387.75	191.47	1186.74	194.73	2574.49
"	3	17:20:05	198.00	1383.75	191.72	1184.69	194.86	2568.45
"	3	17:20:15	198.00	1383.19	191.72	1185.78	194.86	2568.97
"	3	17:20:56	198.00	1380.94	191.72	1190.10	194.86	2571.04
"	3	17:22:14	198.00	1374.10	191.72	1198.54	194.86	2572.65
"	3	17:23:35	198.00	1367.01	191.46	1196.83	194.73	2563.84
"	3	17:24:50	198.57	1378.88	191.22	1195.27	194.90	2574.15
"	3	17:25:45	199.00	1387.72	191.43	1196.51	195.21	2584.23
"	3	17:27:04	198.44	1383.55	191.72	1198.26	195.08	2581.81
"	3	17:27:46	198.14	1381.31	191.72	1202.63	194.93	2583.93
"	3	17:28:05	198.00	1380.29	191.72	1204.60	194.86	2584.89
"	3	17:29:16			191.72	1211.98		
"	3	17:36:26	171.00	869.47				
"	3	17:37:42	170.46	856.96	161.21	663.83	165.83	1520.80
"	3	17:38:28	170.13	849.33	161.21	679.61	165.67	1528.94
"	3	17:38:46	170.00	846.35	161.21	685.79	165.60	1532.13
"	3	17:39:58	170.00	855.97	161.21	710.17	165.60	1566.14
"	3	17:40:59	170.00	864.23	161.21	726.30	165.60	1590.53
"	3	17:42:10			161.21	745.10		

EXXON NASHVILLE SHAFT HORSEPOWER MEASUREMENTS (CONT.)

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-8-77	4	18:55:44	163.50	811.68				
"	4	18:56:57	163.50	827.39	158.67	712.50	161.08	1539.89
"	4	18:57:57	163.50	840.29	158.67	709.82	161.08	1550.11
"	4	18:59:06	163.50	823.99	158.67	706.73	161.08	1530.72
"	4	19:00:00	163.50	811.24	158.67	704.30	161.08	1515.54
"	4	19:01:18	163.27	823.18	158.67	700.84	160.97	1524.02
"	4	19:02:49	163.00	837.26	158.37	716.29	160.69	1553.55
"	4	19:03:54	163.26	829.86	158.16	727.28	160.71	1557.15
"	4	19:04:56	163.50	822.79	157.92	726.07	160.71	1548.86
"	4	19:06:05	162.89	803.48	157.65	724.72	160.27	1528.20
"	4	19:07:45	162.00	775.71	157.65	711.11	159.82	1486.82
"	4	19:08:54	162.60	781.68	157.65	701.71	160.12	1483.40
"	4	19:09:40	163.00	785.68	157.65	695.05	160.32	1480.72
"	4	19:10:53	162.84	779.48	157.65	684.49	160.25	1463.97
"	4	19:13:27	162.50	766.44	157.65	692.16	160.08	1458.60
"	4	19:13:29	162.50	766.27	157.65	692.25	160.07	1458.52
"	4	19:14:38	162.79	767.60	157.65	695.69	160.22	1463.29
"	4	19:15:28	163.00	768.56	157.65	688.50	160.32	1457.06
"	4	19:16:37	163.00	768.52	157.65	678.58	160.32	1447.10
"	4	19:17:43	163.00	768.49	157.41	677.50	160.21	1445.99
"	4	19:18:47	162.79	767.46	157.19	676.48	159.99	1443.94
"	4	19:19:00	162.74	767.24	157.14	676.27	159.94	1443.51
"	4	19:20:13	162.50	766.05	157.39	677.28	159.94	1443.32
"	4	19:21:30	162.24	764.79	157.65	678.34	159.95	1443.14
"	4	19:22:43	162.00	763.61	157.65	661.45	159.82	1425.05
"	4	19:24:17	162.95	764.33	157.65	639.68	160.30	1404.02
"	4	19:24:22	163.00	764.37	157.65	638.53	160.32	1402.90
"	4	19:25:12	163.50	764.74	157.65	647.44	160.57	1412.18
"	4	19:27:32			157.65	672.42		
11-9-77	A	9:25:34	217.00	1875.83				
"	A	9:26:34	217.33	1848.23	212.00	1732.78	214.67	3581.01
"	A	9:28:34	218.00	1792.76	214.00	1687.72	216.00	3480.48
"	A	9:29:34			215.00	1664.76		
"	A	9:31:23	START ASTERN CRASH STOP					
"	A	9:31:53	CLUTCH CHANGE FROM ASTERN TO AHEAD MODE COMPLETED					
"	A	9:33:19	ASTERN CRASH STOP COMPLETED					
11-9-77	5	10:10:16	211.00	1723.22				
"	5	10:11:29	211.00	1723.02	208.00	1615.58	209.50	3338.61
"	5	10:12:41	211.00	1722.84	208.52	1627.35	209.76	3350.18
"	5	10:13:51	211.00	1715.82	209.00	1638.33	210.00	3354.14
"	5	10:15:04	211.00	1708.50	210.19	1641.56	210.59	3350.06
"	5	10:16:52	211.58	1708.80	212.00	1646.39	211.79	3355.19
"	5	10:18:13	212.00	1709.00	212.00	1646.32	212.00	3355.33
"	5	10:19:22	212.49	1724.12	212.00	1646.26	212.24	3370.39

EXXON NASHVILLE SHAFT HORSEPOWER MEASUREMENTS (CONT.)

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-9-77	5	10:20:36	213.00	1739.96	211.03	1642.32	212.01	3382.27
"	5	10:21:52	214.54	1744.66	210.00	1638.12	212.27	3382.78
"	5	10:23:06	216.00	1749.00	210.37	1635.34	213.19	3384.33
"	5	10:25:07	212.88	1728.26	211.00	1630.67	211.94	3358.93
"	5	10:26:22	211.00	1715.69	209.97	1626.53	210.49	3342.21
"	5	10:27:31	211.93	1726.80	209.00	1622.57	210.47	3349.38
"	5	10:28:52	213.00	1739.58	209.52	1626.54	211.26	3366.13
"	5	10:30:05	212.51	1732.00	210.00	1630.21	211.25	3362.21
"	5	10:31:22	212.00	1724.21				
"	5	10:41:23	165.00	759.84				
"	5	10:42:36	165.00	776.51	167.00	807.61	166.00	1584.11
"	5	10:43:57	165.00	795.01	167.00	807.62	166.00	1602.62
"	5	10:45:09	165.00	795.01	167.00	807.62	166.00	1602.63
"	5	10:46:27	165.00	795.01	167.52	841.26	166.26	1636.27
"	5	10:47:40	165.47	808.24	168.00	872.90	166.74	1681.13
"	5	10:49:01	166.00	823.01	168.27	874.31	167.13	1697.32
"	5	10:50:10	166.00	850.68	168.50	875.52	167.25	1726.19
"	5	10:51:24	166.00	880.34	168.74	888.50	167.37	1768.85
"	5	10:52:41	165.50	825.86	169.00	902.07	167.25	1727.92
"	5	10:53:58	165.00	771.68	168.46	863.51	166.73	1635.19
"	5	10:54:34	165.00	771.58	168.00	830.21	166.50	1601.78
"	5	10:56:34	165.00	771.38	168.67	837.45	166.83	1608.83
"	5	10:57:34			169.00	841.07		
11-9-77	6	11:45:13	166.00	811.50				
"	6	11:46:30	166.52	853.31	168.00	791.64	167.26	1644.94
"	6	11:47:43	167.00	892.62	167.49	826.24	167.24	1718.86
"	6	11:48:52	167.48	919.98	167.00	859.18	167.24	1779.16
"	6	11:50:09	168.00	950.28	167.00	877.59	167.50	1827.88
"	6	11:51:24			167.00	895.26		
"	6	11:57:08			207.00	1609.91		
"	6	11:59:00	212.00	1725.14	209.76	1627.91	210.88	3353.05
"	6	12: 0:41	212.00	1728.75	211.39	1638.48	211.70	3367.23
"	6	12: 1:09	212.00	1729.75	213.00	1648.91	212.50	3378.66
"	6	12: 2:22	212.00	1732.35	213.00	1652.60	212.50	3384.96
"	6	12: 3:39	212.00	1728.70	213.00	1656.40	212.50	3385.10
"	6	12: 5:00	212.00	1724.76	210.23	1626.26	211.11	3351.02
"	6	12: 5:09	212.14	1725.89	209.88	1622.57	211.01	3348.46
"	6	12: 6:05	212.93	1732.13	208.00	1602.24	210.46	3334.37
"	6	12: 7:21	214.00	1740.65	208.00	1602.17	211.00	3342.82
"	6	12: 8:38			208.00	1602.11		
"	6	12: 9:52	ABEAM SOUTH RANGE MARK					
"	6	12:10:28	START CRASH STOP					
"	6	12:10:58	CLUTCH CHANGE FROM AHEAD TO ASTERN MODE COMPLETED					
"	6	12:15:23	CRASH STOP COMPLETED					

APPENDIX D

EXXON LAKE CHARLES SHAFT HORSEPOWER MEASUREMENTS

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-10-77	A	21:43:42	START BACKING DOWNSTREAM ASTERN AT MAXIMUM POWER					
"	A	21:44:30	188.50	1075.09				
"	A	21:45:46	189.25	1034.93	194.00	1139.79	191.62	2174.73
"	A	21:47:02	190.00	994.47	193.36	1083.21	191.68	2077.68
"	A	21:47:44			193.00	1052.08		
"	A	21:48:45	START ASTERN CRASH STOP					
"	A	21:49:10	CLUTCH CHANGE FROM ASTERN TO AHEAD MODE COMPLETED					
"	A	21:52:20	CRASH STOP COMPLETED					
11-10-77	1	22:24:01	200.00	1290.34				
"	1	22:25:14	200.00	1287.41	190.00	1117.74	195.00	2405.15
"	1	22:26:26	200.00	1284.52	191.04	1130.00	195.52	2414.53
"	1	22:27:32	199.53	1276.06	192.00	1141.31	195.77	2417.36
"	1	22:28:48	199.00	1266.33	192.00	1135.59	195.50	2401.92
"	1	22:30:04	199.00	1251.87	192.00	1129.88	195.50	2381.74
"	1	22:31:16	199.00	1238.17	192.00	1130.02	195.50	2368.19
"	1	22:32:47	199.00	1221.04	192.00	1130.20	195.50	2351.24
"	1	22:33:52	199.00	1208.79	192.47	1133.06	195.74	2341.85
"	1	22:35:05	199.00	1208.73	193.00	1136.26	196.00	2345.00
"	1	22:36:14	199.00	1208.68	193.00	1136.41	196.00	2345.09
"	1	22:37:22	199.48	1223.11	193.00	1136.55	196.24	2359.66
"	1	22:38:35	200.00	1238.66	193.49	1139.42	196.74	2378.08
"	1	22:39:51	199.02	1229.90	194.00	1142.41	196.51	2372.31
"	1	22:41:10	198.00	1220.83	193.47	1139.45	195.73	2360.28
"	1	22:42:20	198.45	1218.45	193.00	1136.83	195.73	2355.28
"	1	22:43:44	199.00	1215.55	193.55	1140.17	196.27	2355.72
"	1	22:44:53	198.51	1209.77	194.00	1142.92	196.26	2352.69
"	1	22:46:06	198.00	1203.68	194.00	1143.05	196.00	2346.73
"	1	22:48:41			194.00	1143.33		
"	1	22:58:01	156.00	570.73				
"	1	22:59:18	156.00	570.69	158.00	587.54	157.00	1158.23
"	1	23:00:45	156.00	570.66	158.64	611.29	157.32	1181.95
"	1	23:01:58	156.00	582.16	159.00	634.52	157.50	1216.68
"	1	23:03:10	156.00	593.52	158.54	632.85	157.27	1226.36
"	1	23:04:23	156.00	588.75	158.00	630.87	157.00	1219.61
"	1	23:05:46	156.00	584.78	158.00	637.86	157.00	1222.65
"	1	23:07:02	156.00	587.14	158.00	645.34	157.00	1232.48
"	1	23:08:14	156.00	589.38	158.50	647.44	157.25	1236.82
"	1	23:09:27	156.00	602.67	159.00	649.58	157.50	1252.24
"	1	23:10:43	156.00	616.93	158.49	672.11	157.24	1289.04
"	1	23:11:56	156.49	600.95	158.00	693.58	157.25	1294.52
"	1	23:13:08	157.00	584.52	158.00	660.99	157.50	1245.50
"	1	23:14:24	156.52	582.83	158.00	626.58	157.26	1209.41
"	1	23:15:48	156.00	580.96	158.00	629.14	157.00	1210.10
"	1	23:17:05			158.00	631.49		

EXXON LAKE CHARLES SHAFT HORSEPOWER MEASUREMENTS (CONT.)

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD.ENGINE SRPM	STBD.ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-10-77	1	23:28:21	START CRASH STOP					
"	1	23:28:46	CLUTCH CHANGE FROM AHEAD TO ASTERN MODE COMPLETED					
"	1	23:31:11	CRASH STOP COMPLETED					
11-10-77	2	23:54:11	152.00	585.94				
"	2	23:55:30	152.26	577.81	159.50	673.90	155.88	1251.70
"	2	23:56:44	152.50	570.17	159.74	675.10	156.12	1245.27
"	2	23:58:01	151.99	584.16	160.00	656.80	155.99	1240.96
"	2	23:59:15	151.50	597.50	159.76	679.13	155.63	1276.63
11-11-77	2	00:00:35	150.75	594.76	159.50	703.19	155.13	1297.95
"	2	00:01:56	150.00	591.98	159.50	718.57	154.75	1310.55
"	2	00:03:08	150.00	578.88	159.50	732.24	154.75	1311.11
"	2	00:04:20	150.00	565.78	158.75	705.08	154.38	1270.86
"	2	00:05:33	150.00	559.62	158.00	677.77	154.00	1237.39
"	2	00:06:53	150.00	552.87				
"	2	00:10:32	199.00	1298.27	START DOWNSTREAM AHEAD AT MAX.POWER			
"	2	00:11:52	199.00	1276.86	190.00	1126.02	194.50	2402.87
"	2	00:13:23	199.00	1252.51	191.67	1136.12	195.34	2388.63
"	2	00:14:35	199.25	1253.87	193.00	1144.12	196.12	2397.99
"	2	00:15:48	199.50	1255.24	193.00	1147.11	196.25	2402.35
"	2	00:17:01	199.50	1246.73	193.00	1150.09	196.25	2396.83
"	2	00:18:18	199.50	1237.77	193.50	1150.27	196.50	2388.04
"	2	00:19:34	198.75	1218.59	194.00	1150.44	196.37	2369.03
"	2	00:20:50	198.00	1199.53	194.00	1150.54	196.00	2350.07
"	2	00:22:06			194.00	1150.64		
"	2	00:23:43	START AHEAD CRASH STOP (EASY STEPS)					
"	2	00:24:08	CLUTCH CHANGE FROM AHEAD TO ASTERN MODE COMPLETED					
"	2	00:31:19	CRASH STOP COMPLETED					
11-11-77	3	01:31:39	178.50	901.63				
"	3	01:32:52	178.50	868.43	177.00	869.37	177.75	1737.80
"	3	01:34:05	178.50	880.98	177.00	871.40	177.75	1752.38
"	3	01:35:59	177.88	874.08	177.00	874.57	177.44	1748.65
"	3	01:37:09	177.50	869.86	177.00	879.92	177.25	1749.79
"	3	01:38:18	177.50	877.59	177.00	885.20	177.25	1762.79
"	3	01:39:34	177.50	886.10	177.00	874.27	177.25	1760.37
"	3	01:40:47	177.75	874.13	177.00	863.78	177.37	1737.91
"	3	01:42:00	178.00	862.11	177.51	871.66	177.75	1733.77
"	3	01:43:10	178.00	867.43	178.00	879.25	178.00	1746.68
"	3	01:44:27	178.00	873.05	177.74	872.23	177.87	1745.28
"	3	01:45:36	178.00	872.77	177.50	865.94	177.75	1738.72
"	3	01:46:49	178.00	872.48	177.24	875.68	177.62	1748.16
"	3	01:47:58	177.76	873.84	177.00	884.85	177.38	1758.69
"	3	01:49:14	177.50	875.33	177.00	884.81	177.25	1760.14
"	3	01:50:34	177.75	874.02	177.00	884.76	177.37	1758.78
"	3	01:51:55	178.00	872.69	177.00	882.04	177.50	1754.74
"	3	01:53:15	178.16	874.94	177.00	879.36	177.58	1754.30

EXXON LAKE CHARLES SHAFT HORSEPOWER MEASUREMENTS (CONT.)

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-11-77	3	01:56:01	178.50	879.64	177.00	890.73	177.75	1770.37
"	3	01:57:13	177.99	893.35	177.00	895.66	177.49	1789.00
"	3	01:58:22	177.50	906.40	177.00	895.46	177.25	1801.86
"	3	01:59:31	177.98	911.36	177.00	895.26	177.49	1806.62
"	3	02:00:47	178.50	916.84	177.20	887.65	177.85	1804.48
"	3	02:02:41	177.62	899.91	177.50	876.18	177.56	1776.10
"	3	02:04:01	177.00	888.10	177.26	877.53	177.13	1765.63
"	3	02:05:25	177.53	882.36	177.00	878.93	177.27	1761.29
"	3	02:06:38	178.00	877.33	177.00	871.09	177.50	1748.42
"	3	02:07:55	177.49	874.92	177.00	862.81	177.24	1737.73
"	3	02:09:08	177.00	872.64	177.24	871.58	177.12	1744.22
"	3	02:10:28	177.00	872.49	177.50	881.23	177.25	1753.71
"	3	02:11:45	177.00	872.34	177.25	898.41	177.13	1770.75
"	3	02:13:02	177.00	875.06	177.00	916.22	177.00	1791.28
"	3	02:14:22	177.00	877.90	177.00	913.34	177.00	1791.24
"	3	02:15:35	177.23	879.03	177.00	910.71	177.12	1789.75
"	3	02:16:59	177.50	880.35	176.51	965.71	177.01	1846.05
"	3	02:18:27	177.77	931.61	176.00	1023.00	176.88	1954.60
"	3	02:19:44	178.00	976.57	176.49	965.78	177.24	1942.35
"	3	02:21:05			177.00	905.21		
11-11-77	4	03:02:34	176.00	1156.77				
"	4	03:03:46	176.00	934.80	169.00	770.55	172.50	1705.36
"	4	03:05:04	176.00	980.68	168.49	801.87	172.25	1782.54
"	4	03:06:20	176.00	995.58	168.00	832.17	172.00	1827.76
"	4	03:07:40	176.00	1011.28	168.00	835.25	172.00	1846.54
"	4	03:08:57	175.74	975.17	168.00	837.32	171.87	1812.49
"	4	03:10:09	175.50	941.47	168.24	833.54	171.87	1775.02
"	4	03:11:29	176.01	925.93	168.50	829.33	172.26	1755.25
"	4	03:12:45	176.50	911.05				
"	4	03:16:54	153.00	570.41				
"	4	03:18:02	153.19	574.60	151.50	552.82	152.35	1127.42
"	4	03:19:49	153.50	581.23	151.50	547.37	152.50	1128.59
"	4	03:21:02	153.50	574.37	151.50	543.65	152.50	1118.02
"	4	03:22:14	153.50	567.61	151.50	544.37	152.50	1111.98
"	4	03:23:27	153.50	563.10	151.50	552.75	152.50	1115.85
"	4	03:24:40	153.50	558.60	151.26	551.78	152.38	1110.38
"	4	03:25:57	153.50	560.95	151.00	550.76	152.25	1111.71
"	4	03:27:10	153.50	563.18	151.25	549.36	152.37	1112.55
"	4	03:28:23	153.50	560.91	151.50	547.96	152.50	1108.88
"	4	03:29:39	153.50	558.55	151.07	548.31	152.29	1106.86
"	4	03:31:22			150.50	548.77		
11-11-77	5	04:43:39	200.00	1299.54				
"	5	04:44:48	199.64	1309.14	192.00	1150.52	195.82	2459.66
"	5	04:46:53	199.00	1269.70	192.65	1143.03	195.82	2412.73
"	5	04:48:01	198.53	1247.68	193.00	1138.91	195.76	2386.59

EXXON LAKE CHARLES SHAFT HORSEPOWER MEASUREMENTS (CONT.)

DATE	TEST RUN	TIME	PORT ENGINE SRPM	PORT ENGINE SHP	STBD. ENGINE SRPM	STBD. ENGINE SHP	BOTH ENGINES SRPM	BOTH ENGINES SHP
11-11-77	5	04:49:17	198.00	1223.18	193.38	1145.51	195.69	2368.70
"	5	04:51:21	198.61	1222.91	194.00	1156.32	196.30	2379.23
"	5	04:52:41	199.00	1222.73	195.09	1153.14	197.04	2375.87
"	5	04:53:48	199.00	1230.92	196.00	1150.40	197.50	2381.31
"	5	04:55:05	199.00	1240.32	194.97	1147.38	196.99	2387.71
"	5	04:56:18	199.00	1223.44	194.00	1144.49	196.50	2367.94
"	5	04:57:35	199.00	1205.65	192.99	1144.38	196.00	2350.04
"	5	04:58:51	199.50	1226.18	192.00	1144.22	195.75	2370.40
"	5	05:00:07	200.00	1246.80	190.47	1126.20	195.23	2372.99
"	5	05:01:20	199.50	1226.17	189.00	1109.03	194.25	2335.19
"	5	05:02:32	199.00	1205.89	190.38	1119.80	194.69	2325.69
"	5	05:03:56	199.00	1246.14	192.00	1132.40	195.50	2378.54
"	5	05:05:09	199.00	1281.12	191.51	1129.44	195.25	2410.56
"	5	05:06:24	199.00	1287.16	191.00	1126.40	195.00	2413.56
"	5	05:07:37	199.00	1293.04	191.39	1128.66	195.19	2421.70
"	5	05:09:31			192.00	1132.18		
11-11-77	6	05:35:54	STARTING UPSTREAM ASTERN RUN AT MAXIMUM POWER					
"	6	05:40:05	187.00	1044.73				
"	6	05:41:22	187.25	1059.49	192.00	1054.01	189.62	2113.50
"	6	05:42:39	187.50	1074.27				
"	6	05:51:36	189.00	1249.66	START DOWNSTREAM ZIG-ZAG RUN			
"	6	05:52:48	191.90	1266.18	184.00	1105.68	187.95	2371.86
"	6	05:54:05	195.00	1283.74	187.92	1123.63	191.46	2407.37
"	6	05:55:25	196.48	1273.22	192.00	1142.03	194.24	2415.26
"	6	05:56:47	198.00	1262.13	193.06	1142.09	195.53	2404.23
"	6	05:57:59	198.47	1265.43	194.00	1142.08	196.24	2407.51
"	6	05:59:19	199.00	1269.09	191.97	1133.07	195.49	2402.16
"	6	06:00:37	199.00	1251.70	190.00	1124.24	194.50	2375.94
"	6	06:01:56	199.00	1234.11	191.03	1124.33	195.02	2358.43
"	6	06:03:10			192.00	1124.35		
"	6	06:04:55	START CRASH STOP					
"	6	06:05:20	CLUTCH CHANGE FROM AHEAD TO ASTERN MODE COMPLETED					
"	6	06:11:11	CRASH STOP COMPLETED					

APPENDIX E

FUEL CONSUMPTION MEASUREMENTS (DIESEL OIL)

EXXON NASHVILLE TESTS

DATE	TEST RUN	START TIME	ELAPSED TIME	FUEL CONSUMPTION PORT	STBD.	BOTH
		(hh:mm:ss)	(mm:ss)	(lbs)	(lbs)	(lbs)
11-8-77	1	14:27:18	13:50	148	147	295
"	2	15:37:00	8:00	55	38	93
"	2	15:55:48	8:47	95	90	185
"	3	17:12:12	15:30	129	118	247
"	3.	17:38:28	8:20	43	34	77
"	4	19:13:27	10:54	54	50	104
11-9-77	5	10:16:49	15:40	168	162	330
"	6	12:00:41	9:11	98	95	193

EXXON LAKE CHARLES TESTS

11-10-77	1	22:32:09	16:07	129	121	250
11-11-77	2	00:13:19	9:23	75	68	143
"	3	01:35:57	18:46	105	106	211
"	4	03:19:36	11:20	42	42	84
"	5	04:51:02	18:07	147	137	284
"	6	05:54:54	9:53	82	73	155

APPENDIX F

Sample of Tow Performance Data Base

(From EXXON NASHVILLE trials - Run 1)

The following 4 pages show the tabular format containing the tow data. Page F-2 should be consulted as to the meaning of the column numbers on pages F-3 through F-5.

The data is from the first EXXON NASHVILLE full power run over the straight course area and is printed at 30 second intervals. The sample output is included to assist the reader in understanding the numeric character of the data base.

TEST DESCRIPTION

Upstream full Power ahead run. Full set of data measurements obtained. Data recorded between north range and 190 Bridge.

PARAMETER FILE NAME = PN12.DAT DATA FILE NAME = TN12.DAT TEST DATE = 11.08.77 TEST START TIME = 14.27.00
TEST END TIME = 14.46.59 TOTAL NUMBER OF SECONDS OF DATA = 1200

TIME CORRECTION FACTORS(SEC.): DATALOGGER<START= 0><END= -6>; PH MINIRANGR<START=-67><END=-65>; BOW MINIRANGR<START= 28><END= 29>

TRANSPONDER POSITIONS:
XPNDR 1 X=51046.29 Y=46010.37; XPNDR 2 X=66815.44 Y=44064.84; XPNDR 3 X=74309.91 Y=42901.99; XPNDR 4 X=76024.98 Y=39756.65

NO.	VARIABLE DESCRIPTION	NO.	VARIABLE DESCRIPTION
1	...TOWBOAT MINIRANGER RANGE, CHANNEL A, METERS	22	...TOW CG ACCELERATION, Y DIRECTION, OVER GRND, FT/SEC/SEC
2	...TOWBOAT MINIRANGER RANGE, CHANNEL B, METERS	23	...RESULTANT TOW CG ACCELERATION, OVER GROUND, FT/SEC/SEC
3	...BOW MINIRANGER RANGE, CHANNEL A, METERS	24	...YAW ACCELERATION, DEGREES/SEC/SEC
4	...BOW MINIRANGER RANGE, CHANNEL B, METERS	25	...STEERING RUDDER ANGLE, DEGREES
5	...ADJUSTED TOWBOAT RANGE, CHANNEL A, METERS	26	...FLANKING RUDDER ANGLE, DEGREES
6	...ADJUSTED TOWBOAT RANGE, CHANNEL B, METERS	27	...PORT ENGINE SHAFT HORSEPOWER, SHP
7	...ADJUSTED BOW RANGE, CHANNEL A, METERS	28	...PORT SHAFT RPM
8	...ADJUSTED BOW RANGE, CHANNEL B, METERS	29	...STARBOARD ENGINE SHAFT HORSEPOWER, SHP
9	...X POSITION OF TOWBOAT ANTENNA, (LAMBERT Y -6E+5), FEET	30	...STARBOARD SHAFT RPM
10	...Y POSITION OF TOWBOAT ANTENNA, (LAMBERT X -2E+6), FEET	31	...TOTAL SHAFT HORSEPOWER, BOTH ENGINES
11	...X POSITION OF BOW ANTENNA, (LAMBERT Y -6E+5), FEET	32	...AVERAGE SHAFT RPM, BOTH SHAFTS
12	...Y POSITION OF BOW ANTENNA, (LAMBERT X -2E+6), FEET	33	...CURRENT VELOCITY AT STERN, X DIRECTION, FT/SEC
13	...X POSITION OF CG, (LAMBERT Y -6E+5), FEET	34	...CURRENT VELOCITY AT STERN, Y DIRECTION, FT/SEC
14	...Y POSITION OF CG, (LAMBERT X -2E+6), FEET	35	...CURRENT VELOCITY AT BOW, X DIRECTION, FT/SEC
15	...HEADING ANGLE, 0 - 360, NORTH = POSITIVE X, DEGREES	36	...CURRENT VELOCITY AT BOW, Y DIRECTION, FT/SEC
16	...VELOCITY OF TOW AT CG, X DIRECTION, OVER GROUND, FT/SEC	37	...DEPTH OF WATER AT STERN, FEET
17	...VELOCITY OF TOW AT CG, Y DIRECTION, OVER GROUND, FT/SEC	38	...DEPTH OF WATER AT BOW, FEET
18	...RESULTANT VELOCITY OF TOW AT CG, OVER GROUND, FT/SEC	39	...TOWBOAT DISTANCE OFF WEST/SOUTH BANK, FEET
19	...YAW RATE, DEGREES/SECOND	40	...TOWBOAT DISTANCE OFF EAST/NORTH BANK, FEET
20	...DRIFT ANGLE, DEGREES	41	...BOW DISTANCE OFF WEST/SOUTH BANK, FEET
21	...TOW CG ACCELERATION, X DIRECTION, OVER GRND, FT/SEC/SEC	42	...BOW DISTANCE OFF EAST/NORTH BANK, FEET

HHMMSS	SECS	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(25)	(26)
------	----																
142700	1	0	0	0	0	1093.4	4353.2	1256.1	4040.0	52589.5	42772.1	53622.5	42787.7	53106.5	42780.4	-.4	.7
142730	31	1152	4237	1338	3919	1149.4	4237.3	1337.6	3919.7	52972.1	42768.0	54016.4	42781.5	53489.3	42775.1	4.4	.6
142800	61	1220	4117	1424	3799	1214.2	4118.1	1422.3	3802.7	53365.8	42771.3	54406.3	42779.8	53882.8	42776.1	1.7	.5
142830	91	0	3998	0	3682	1286.4	3998.9	1509.3	3682.3	53758.3	42780.1	54802.2	42781.6	54275.5	42781.4	1.7	.6
142900	121	0	3881	1601	3564	1366.9	3880.4	1598.9	3563.5	54149.6	42774.0	55193.4	42793.6	54666.6	42784.2	2.3	.7
142930	151	1455	3763	1700	3443	1451.0	3761.4	1696.8	3444.2	54542.5	42780.2	55586.2	42791.9	55059.6	42786.5	3.5	.7
143000	181	1537	3644	1793	3325	1538.7	3643.3	1796.0	3323.0	54932.8	42785.4	55982.3	42792.4	55450.0	42789.1	1.0	.7
143030	211	1638	3523	1898	3208	1634.9	3525.2	1896.1	3208.4	55323.4	42774.0	56368.0	42787.7	55840.6	42781.5	2.2	.5
143100	241	0	3407	2000	3091	1731.2	3406.0	1999.0	3090.7	55715.9	42772.2	56758.5	42784.0	56232.9	42778.6	-.8	.7
143130	271	1831	3290	2105	2972	1830.9	3288.7	2102.5	2972.1	56105.2	42769.1	57148.3	42792.9	56622.1	42781.4	-.8	.7
143200	301	1939	3166	2208	2851	1935.4	3168.1	2207.8	2853.2	56502.4	42764.0	57537.6	42800.9	57019.1	42782.9	4.9	.5
143230	331	2039	3051	2311	2736	2035.4	3050.3	2314.7	2736.1	56891.5	42773.6	57926.8	42801.1	57408.3	42787.7	1.4	.6
143300	361	2142	2936	2424	2621	2139.6	2933.9	2421.7	2621.4	57276.7	42771.5	58310.9	42796.0	57793.6	42784.4	1.5	.6
143330	391	0	0	2529	2504	2244.5	2817.9	2528.4	2505.1	57662.9	42776.9	58696.8	42799.0	58180.0	42788.5	5.8	.3
143400	421	2355	2698	0	0	2351.1	2699.9	2637.0	2388.1	58050.2	42780.3	59083.1	42798.1	58567.3	42789.6	.9	.6
143430	451	2462	2581	2748	2270	2458.0	2583.5	2748.7	2270.6	58435.9	42780.4	59471.1	42803.8	58952.9	42792.6	8.9	.4
143500	481	2569	2466	2858	2153	2564.8	2467.3	2858.3	2156.3	58821.3	42784.8	59855.2	42796.0	59338.7	42790.9	.8	.6
143530	511	2678	2350	2972	2043	2675.7	2351.0	2969.7	2041.5	59208.7	42781.3	60241.4	42787.6	59726.0	42784.8	1.4	.6
143600	541	2790	2233	3077	1928	2790.3	2235.1	3082.1	1925.5	59595.8	42769.7	60629.7	42790.4	60113.0	42780.7	1.8	.6
143630	571	2900	2117	3198	1806	2899.6	2119.1	3194.1	1808.8	59984.4	42765.8	61017.3	42789.7	60501.1	42778.4	-.3	.6
143700	601	3011	2003	3309	1688	3009.1	2003.9	3306.9	1689.9	60373.4	42752.2	61412.3	42808.6	60889.7	42780.6	3.7	.7
143730	631	3121	1888	0	1575	3115.2	1888.0	3421.9	1576.0	60756.4	42772.2	61801.8	42797.7	61274.5	42785.0	5.2	.6
143800	661	3233	1774	0	1464	3233.1	1772.7	3536.4	1462.4	61145.7	42786.0	62192.5	42789.1	61662.5	42788.3	9.7	.3
143830	691	0	1654	0	1351	3342.9	1655.2	3650.5	1352.2	61535.7	42804.6	62575.0	42765.4	62052.5	42785.6	-2.0	.4
143900	721	0	1541	0	1242	3457.8	1541.3	3763.9	1243.9	61922.9	42800.6	62956.1	42725.2	62438.0	42763.9	-.1	.3
143930	751	3674	1431	3341	1141	3670.2	1430.6	3340.8	1139.9	62269.0	42882.9	63352.2	42654.9	62775.8	42776.0	3.5	.5
144000	781	3559	1323	3221	1036	3555.2	1321.7	3221.6	1037.9	62650.8	42843.2	63744.1	42597.6	63156.7	42729.3	3.5	.4
144030	811	0	0	0	937	3428.0	1215.3	3103.4	938.0	63066.0	42713.4	64134.5	42553.5	63577.6	42637.4	.9	.4
144100	841	3302	1108	0	0	3306.4	1110.0	2988.3	843.5	63463.9	42642.0	64514.1	42527.9	63978.0	42586.4	3.2	.5
144130	871	3186	1008	0	756	3190.5	1009.1	2868.5	755.9	63846.8	42600.6	64906.7	42480.8	64361.0	42542.8	-.6	.4
144200	901	3071	911	2750	675	3069.5	911.6	2750.2	677.3	64246.0	42539.6	65298.4	42438.1	64761.0	42490.5	5.8	.0
144230	931	2946	813	2631	613	2947.4	815.1	2631.8	614.4	64647.8	42495.8	65690.8	42395.5	65163.0	42446.7	6.1	.4
144300	961	0	0	0	0	2826.3	728.5	2512.3	567.8	65047.9	42455.5	66085.8	42350.0	65562.3	42403.6	-2.6	.0
144330	991	0	0	0	0	2705.9	655.3	2393.0	546.8	65445.4	42407.3	66481.4	42302.8	65960.0	42355.8	1.6	.6
144400	1021	0	0	0	0	2588.4	600.7	2274.6	551.2	65836.0	42354.6	66874.9	42257.0	66350.9	42306.7	5.2	.4
144430	1051	0	0	0	0	2472.1	567.0	2159.6	578.0	66222.0	42301.7	67257.3	42220.1	66737.6	42261.6	8.2	.7
144500	1081	0	551	0	0	2357.2	553.1	2047.7	625.6	66602.7	42263.0	67630.1	42180.2	67118.0	42222.0	.6	1.0
144530	1111	0	0	1934	687	2247.1	565.1	1934.6	688.9	66969.3	42217.0	68007.2	42145.7	67485.2	42182.1	2.3	.8
144600	1141	0	0	0	0	2139.0	597.3	1825.6	759.0	67329.5	42174.5	68371.1	42120.9	67846.0	42148.4	1.8	.4
144630	1171	2032	640	0	0	2035.3	639.3	1723.7	835.6	67673.7	42151.3	68713.2	42088.4	68189.7	42120.6	23.1	.0

HHMMSS	SECS	(15)	(19)	(24)	(20)	(16)	(17)	(18)	(21)	(22)	(23)	(27)	(28)	(29)	(30)	(31)	(32)
------	----																
142700	1	.81	-.039	-.0003	5.294	12.64	-.99	12.69	-.001	.002	.003	1715	213.4	1600	222.3	3314	217.8
142730	31	.68	.010	-.0033	.424	12.90	.05	12.90	.039	-.042	.057	1713	212.5	1599	217.3	3312	214.9
142800	61	.41	.015	.0069	.033	12.99	.08	12.99	.016	.046	.049	1711	213.4	1599	216.5	3310	214.9
142830	91	.03	.029	-.0025	-.169	13.10	.04	13.10	-.013	.036	.039	1709	213.4	1600	216.6	3309	215.0
142900	121	1.03	-.053	-.0112	2.727	13.05	-.39	13.05	-.023	-.002	.024	1707	226.5	1603	233.7	3310	230.1
142930	151	.58	-.042	-.0026	1.638	13.02	-.24	13.02	-.039	-.021	.045	1705	213.0	1606	214.0	3311	213.5
143000	181	.33	.048	-.0037	-1.611	13.23	.45	13.24	.007	-.117	.117	1707	213.1	1609	209.8	3316	211.5
143030	211	.70	.015	-.0008	1.826	12.78	-.25	12.78	.020	.060	.063	1708	214.3	1611	208.3	3320	211.3
143100	241	.59	.032	.0076	2.129	12.92	-.35	12.92	-.042	.030	.052	1710	214.9	1612	208.3	3322	211.6
143130	271	1.25	.075	.0035	-.029	12.96	.29	12.97	-.017	-.007	.018	1712	212.9	1612	208.0	3324	210.5
143200	301	1.98	-.008	-.0035	1.462	13.80	.13	13.80	-.085	.023	.089	1713	213.2	1612	211.8	3325	212.5
143230	331	1.47	.017	.0091	-.199	13.02	.38	13.02	-.037	-.062	.072	1713	213.1	1611	205.3	3324	209.2
143300	361	1.30	-.024	.0102	1.748	12.86	-.10	12.86	-.018	.092	.094	1713	213.7	1612	203.7	3324	208.7
143330	391	1.17	-.039	.0008	.884	12.95	.06	12.95	.022	.011	.024	1713	212.8	1614	201.2	3327	207.0
143400	421	.93	.001	.0018	1.945	13.06	-.23	13.06	-.017	-.060	.062	1713	212.6	1616	203.3	3330	208.0
143430	451	1.24	.020	.0045	-1.225	12.75	.55	12.76	-.039	.016	.043	1711	212.9	1619	201.5	3331	207.2
143500	481	.57	-.018	-.0020	.312	12.77	.05	12.77	.068	-.003	.068	1710	213.5	1622	201.2	3332	207.4
143530	511	.29	.025	.0160	2.685	13.00	-.54	13.01	.050	-.003	.051	1708	213.9	1624	200.2	3332	207.0
143600	541	1.09	.013	-.0043	2.722	12.91	-.37	12.91	.060	.048	.077	1706	213.3	1623	197.9	3329	205.6
143630	571	1.27	.060	-.0132	3.336	13.00	-.47	13.01	-.065	.077	.102	1704	213.2	1622	195.4	3326	204.3
143700	601	3.05	.003	.0029	.509	13.07	.58	13.08	-.029	-.045	.054	1702	212.2	1620	194.3	3323	203.2
143730	631	1.34	.010	.0403	-.054	12.98	.32	12.98	.165	-.089	.188	1701	213.1	1620	195.3	3321	204.2
143800	661	.11	-.171	-.0251	-3.827	12.24	.84	12.27	-.171	.055	.180	1698	212.2	1621	193.3	3320	202.7
143830	691	357.79	-.079	-.0030	-1.159	12.90	-.24	12.90	-.017	-.018	.025	1697	219.1	1623	198.6	3320	208.9
143900	721	355.77	-.302	-.0492	-3.460	12.13	-.16	12.13	-.335	.213	.397	1698	229.9	1625	217.5	3323	223.7
143930	751	348.06	.277	.0299	7.646	15.29	-5.44	16.23	.344	-.425	.547	1699	229.9	1627	215.2	3326	222.6
144000	781	347.29	-.235	.0492	-13.524	11.56	.16	11.56	.548	-.496	.739	1701	210.3	1628	191.7	3329	201.0
144030	811	351.43	.027	-.0078	6.407	14.67	-3.92	15.18	.049	.012	.051	1702	219.1	1628	203.3	3331	211.2
144100	841	353.74	.088	-.0124	.489	13.39	-1.58	13.48	-.080	-.121	.146	1704	213.0	1628	190.3	3332	201.6
144130	871	353.49	.051	.0003	1.172	13.35	-1.80	13.47	.039	-.024	.046	1704	216.5	1628	199.0	3332	207.7
144200	901	354.44	.034	-.0063	1.189	14.35	-1.70	14.45	.013	.040	.042	1705	211.5	1628	190.0	3333	200.7
144230	931	354.45	.037	.0051	1.087	13.37	-1.55	13.46	.075	-.022	.078	1704	207.0	1628	193.5	3332	200.2
144300	961	354.14	-.027	-.0018	.909	12.97	-1.54	13.06	.009	-.026	.027	0	213.5	0	188.0	0	200.7
144330	991	354.19	.006	-.0001	1.237	13.16	-1.63	13.26	-.019	-.002	.019	0	204.0	0	169.3	0	186.6
144400	1021	354.58	.021	-.0001	1.702	12.92	-1.61	13.02	.013	-.002	.013	0	178.0	0	162.2	0	160.1
144430	1051	355.44	.009	-.0026	1.232	12.85	-1.30	12.91	-.007	.002	.008	0	200.0	0	159.4	0	179.7
144500	1081	355.34	-.000	.0016	1.851	12.19	-1.43	12.57	-.035	-.003	.035	0	200.5	0	160.9	0	180.7
144530	1111	356.01	.034	.0004	1.705	12.06	-1.20	12.12	.008	.004	.010	0	166.8	0	153.5	0	160.1
144600	1141	357.00	.002	-.0026	2.276	11.94	-1.10	11.99	-.034	.002	.034	0	183.3	0	155.4	0	169.4
144630	1171	356.49	-.022	.0033	1.265	11.11	-.93	11.15	-.060	.019	.063	0	211.2	0	174.6	0	192.9

HHMMSS	SECS	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)
142700	1	-3.01	.50	-3.59	.42	40	34	1273	1688	1373	1571
142730	31	-3.23	.47	-3.78	.40	41	38	1240	1670	1297	1569
142800	61	-3.44	.44	-3.95	.37	42	41	1207	1653	1227	1564
142830	91	-3.64	.41	-4.10	.35	43	44	1175	1636	1163	1559
142900	121	-3.82	.39	-4.25	.33	44	47	1143	1620	1106	1552
142930	151	-3.99	.36	-4.38	.31	46	49	1112	1604	1054	1543
143000	181	-4.14	.34	-4.50	.29	47	51	1081	1589	1009	1533
143030	211	-4.29	.32	-4.61	.27	48	53	1050	1574	970	1521
143100	241	-4.42	.30	-4.71	.25	49	54	1020	1560	937	1508
143130	271	-4.54	.28	-4.79	.24	51	55	974	1553	910	1493
143200	301	-4.65	.26	-4.87	.22	53	56	935	1543	889	1477
143230	331	-4.74	.25	-4.93	.21	54	56	902	1532	875	1459
143300	361	-4.82	.23	-4.97	.20	55	55	876	1518	878	1419
143330	391	-4.89	.22	-5.01	.19	56	54	856	1503	893	1367
143400	421	-4.95	.20	-5.03	.18	56	52	843	1486	907	1326
143430	451	-4.99	.19	-5.04	.17	55	51	848	1441	920	1298
143500	481	-5.03	.18	-5.04	.16	54	49	860	1394	931	1283
143530	511	-5.05	.17	-5.03	.15	52	48	873	1357	941	1279
143600	541	-5.05	.17	-5.00	.15	51	47	886	1330	949	1288
143630	571	-5.05	.16	-4.97	.15	49	47	900	1313	969	1334
143700	601	-5.03	.15	-4.92	.15	48	46	915	1307	984	1386
143730	631	-5.00	.15	-4.86	.14	47	45	932	1311	991	1437
143800	661	-4.96	.15	-4.78	.15	46	44	978	1337	991	1488
143830	691	-4.90	.15	-4.70	.15	45	44	1012	1369	982	1539
143900	721	-4.83	.15	-4.60	.15	44	43	1034	1404	959	1597
143930	751	-4.75	.15	-4.49	.15	43	41	1043	1445	906	1673
144000	781	-4.66	.15	-4.36	.16	42	40	1039	1489	857	1740
144030	811	-4.55	.15	-4.23	.17	41	39	1023	1539	810	1797
144100	841	-4.44	.16	-4.08	.17	40	38	994	1592	766	1845
144130	871	-4.31	.16	-3.92	.18	39	37	952	1651	725	1882
144200	901	-4.16	.17	-3.75	.19	38	36	898	1714	688	1910
144230	931	-4.01	.18	-3.66	.20	37	36	831	1781	653	1928
144300	961	-3.84	.19	-3.66	.20	37	36	752	1853	621	1936
144330	991	-3.66	.20	-3.66	.20	36	35	660	1930	593	1934
144400	1021	-3.66	.20	-3.66	.20	35	35	660	1930	567	1922
144430	1051	-3.66	.20	-3.66	.20	35	36	660	1930	545	1901
144500	1081	-3.66	.20	-3.66	.20	34	36	660	1930	525	1869
144530	1111	-3.66	.20	-3.66	.20	34	37	660	1930	509	1828
144600	1141	-3.66	.20	-3.66	.20	33	38	660	1930	495	1777
144630	1171	-3.66	.20	-3.66	.20	33	39	660	1930	485	1716

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Schulz, Roger M
River tow behavior in waterways; Report 2: Second Exxon test program / by Roger M. Schulz, R. M. Schulz Associates, Lafayette, Calif. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
xii, 134, [19] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-17, Report 2)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-77-C-0086.
References: p. 134.

1. Exxon test program. 2. Towboats. 3. Tows and towing. 4. Waterways (Transportation). I. Schulz (R. M.) Associates. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-78-17, Report 2.
TA7.W34 no.H-78-17 Report 2

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